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MECHANICAL PROPERTIES OF ROTARY FORGED SOLID ESR PREFORMS

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Rotary Forging
Steel

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Electro Slag Refined steel which had been rotary forged from a solid 20 inch cast ingot into a solid 13 inch diameter cylinder was evaluated metallographically and mechanically. It is shown that the degree of working is not uniform across the cross section, being greatest near the ID and least near the center. This degree of working manifests itself in the ductility but not in the strength or impact toughness. Normalizing, prior to quench and temper, lowered the yield strength slightly, but markedly improved both the toughness and ductility.

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INTRODUCTION

Initially, rotary forged 105mm M68 tubes were produced from Electro-Slag Refined (ESR) steel. Solid cast 20 inch diameter ingots were rotary forged into 13 inch diameter double length preforms, cut in half lengthwise, trepanned and rotary forged into M68 tubes. While this technique was successful for producing tubes, attempts to use the material in the solid preform state without additional forging, met with mixed mechanical property results. Therefore, end discs were taken from several preforms, subjected to a series of heat treatments, and evaluated.

PROCEDURE

One-inch thick discs were taken from one end of twelve solid ESR preforms. The discs were sectioned into two semi-circular halves. A heat treatment scheme was developed wherein one half of each disc was normalized and heat treated, and the second half was heat treated without normalizing. The heat treatment schedule is given below:

Normalized (where specified)- 1650°F - 2 hrs - Air Cooled

Austenitize - 1550°F - 2 hrs - Water Quenched

Temper - 1050°F - 2 hrs - Water Quenched

Specimens were evaluated at three radial positions, viz., preform center, mid-radius and one inch from the OD. The orientation of all specimens was transverse with the Charpy V-Notch (CVN) toward the center (similar to that used in gun tube forging evaluation). Specimen location and identification are shown in Figure 1.

RESULTS

The results for the normalized and non-normalized preforms are shown in Tables 1-2, respectively. When the study was run, there was an interest in CVN data at room temperature (R.T.), rather than at -40°F, as is done on tubes. Thus, a direct comparison of preform and tube data is not possible. However, it is possible to evaluate or relate:

a. Effect of normalizing on the preform

b. Effect of position in the preform

DISCUSSION

a. Effect of Normalizing

The YS, RA and CVN (R.T.) properties for the normalized steel are shown in Table 1 and plotted against those for the non-normalized steel (Table 2), by position in the preform disc in Figures 2-10. Several observations are possible:

(1) The yield strength of the normalized steel is consistently lower, regardless of position in the preforms (Figs. 2-4). This is true despite the fact that the tempering cycles were the same, and that the normalized steel was tempered with non-normalized steel.

(2) Similarly, there is a fairly consistent, but very small, difference; in the RA, with the normalized steel showing slightly higher RA values (Figs. 5-7). The closeness of the RA values can more readily be seen if the instances of very low RA's seen in some of non-normalized test bars are discounted. If this is done, the average RA's by position in the disc are:

	Center	Mid-Rad	OD
Normalized	33%	41%	43%
Non-normalized	33	38	40

(3) There is a consistent improvement in room temperature CVN. The range of differences runs from 1 ft-lb to 12 ft-lbs with the normalized steel being higher (Figs 8-10). Even if the yield strength factor is taken into account, the data show that normalizing, even at the relatively low temperature used (1650°F) is effective in the forged ESR steel.

b. Effect of Position in the Preform Disc

Using Figs. 2-10, it is possible to show the effect of position in the preform. There is a slight increase in yield strength from the center to the OD, with the change being greater for the non-normalized steel. There is an even more noticeable effect on the RA. Despite the increasing strength, the RA also increases from the center to the OD. The RA values showed several anomalies, particularly in the non-normalized steel. As noted in the tabularized data, there were cases where the test bar itself was cracked prior to testing. These values were ignored in computing the average RA's shown previously. However, there were instances of very low RA's, i.e., 15% or 18% which were seen at the center of several non-normalized discs, but not in any normalized discs.

The effect of position on CVN (RT) is not so clear. There is not a systematic change as one progresses from the center to the OD. There are differences, but there are as many instances of higher center values as there are of lower values.

c. Metallographic Analysis

Sections from two preforms were evaluated for microstructure, inclusion count and residual dendritic structure, to note the effects if any, of normalizing, and of position in the preform. The observations are shown in Figs. 11-20. All exhibit a tempered martensite microstructure, attesting to the adequacy of the quench. However, the same photomicrographs show evidence of microcracking associated with large inclusions and/or voids. These phenomena were seen in center and mid-radius test bars but not in specimens taken near the OD.

The residual dendritic structure can be used to qualitatively evaluate the relative working during the forging operation. As the amount of working increases, the dendrites should become closer spaced and more ordered. By comparing the photomicrographs it appears that the center was worked less than the mid-radius, which, in turn, was worked less than the OD. This is probably not surprising, but certainly shows the danger of assuming a uniform working throughout the cross section. It also demonstrates the inadequacy of using forging ratio or reduction in cross sectional area values. Usually, forging ratio is simply the geometric ratio of the starting cross sectional area and the finishing cross sectional area. In this case, a circular cross section of 20" diameter is reduced to a circular cross section of 13" diameter, i.e., a forging 2.4:1. From a metallurgical standpoint, considering the working at specific positions in the cross section, the ratio is meaningless.

The metallographic observation can be used to rationalize some of the mechanical property results. The RA is seen to increase from the center to the OD. In turn, voids and/or large inclusions are prevalent at the center but not near the OD. The deleterious effect of these perturbations on the RA is well known. This probably accounts not only for the generally lower ductility at the center, but also for the several instances of very low RA, (e.g., 15% or 18%).

The apparently greater actual working near the OD, as seen by the change in residual dendritic pattern does not appear to affect the other properties measured. The average CVN and YS do not change from the center to the OD. Only the RA changed consistently; but this is probably due to the voids and/or inclusions cited previously.

While the normalizing treatment affected all the properties, it does not cause any optically observable change.

CONCLUSIONS

Several conclusions can be drawn, based on these results:

a. The amount of working is not uniform throughout the cross section of the preform, as evidenced by observation of the residual dendritic structure.

b. Normalizing affects all the mechanical properties measured.

c. Location in the preform had no effect on yield strength or CVN (R.T.), but there was a consistent effect on ductility. The average RA increased from the center to the OD with the largest difference seen between the center and the mid-radius.

d. Voids and/or large inclusions probably account for the change in RA, and for the several very low RA values. The metallographic examination shows the material at the OD to be sounder and cleaner than that near the center and mid-radius.

e. The relatively poor material at the center is no cause for concern as far as producing tube forgings is concerned since the center material is removed by trepanning prior to rotary forging. All the preforms on which these tests were made were subsequently successfully rotary forged into 105mm M68 tube forgings.

TABLE 1

MECHANICAL PROPERTIES (NORMALIZED)

	CENTER			MID-RADIUS			OD		
PREFORM NO.	YS[1]	RA[2]	CVN[3]	YS	RA	CVN	YS	RA	CVN
0257	167	32	28	164	45	32	163	43	35
						34	169	54	31
							167	47	
0258	165	36	39	161	42	34	167	48	34
						36	166	54	33
							163	47	
0259	166	27	44	166	45	41	166	48	45
						43	169	53	36
							170	53	
0260	166	36	48	167	50	45	167	56	47
						45	166	59	48
							167	58	
0269	168	33	34	167	38	34	164	47	37
						35	164	50	30
							167	50	
0270	164	42	43	166	38	37	167	46	36
						37	170	54	38
							169	56	

1-ksi
2-Percent
3-Ft-Lbs

TABLE 1 (cont'd)...MECHANICAL PROPERTIES (NORMALIZED)

	CENTER			MID-RADIUS			OD		
PREFORM NO.	YS[1]	RA[2]	CVN[3]	YS	RA	CVN	YS	RA	CVN
0271	166	32	37	166	26	36 41	164 167 168	30 46 47	37 36
0272	165	36	39	166	45	40 40	165 168 169	52 58 56	41 42
0283	164	28	34	163	39	30 31	164 168 167	37 43 51	29 34
0284	155	26	33	163	43	28 32	163 169 169	45 53 53	30 28
0323	166	36	36	162	43	36 36	162 165 166	47 50 52	37 34
0324	166	32	30	165	42	29 29	167 166 164	48 52 52	31 30

TABLE 2

MECHANICAL PROPERTIES (NON-NORMALIZED)

	CENTER			MID-RADIUS			OD		
PREFORM NO.	YS[1]	RA[2]	CVN[3]	YS	RA	CVN	RS	RA	CVN
0257	168	31	26	173	43	32 27	172 174 176	40 45 45	27 30
0258	172	24	38	170	41	30 26	172 164 173	43 7 48	29 27
0259	170	33	40	170	31	34 36	173 (4) 170	55 (4) 37	33 40
0260	164	31	36	171	40	37 35	172 175 172	48 55 56	37 39
0269	174	5	26	170		29 28	174 176 176	(4) 46 48	26 33
0270	165	41	37	170	33	33 31	173 175 176	42 51 48	33 31

1-ksi
2-Percent
3-Ft-Lbs
(4)-Cracked test bar

TABLE 2 (cont'd)- MECHANICAL PROPERTIES (NON-NORMALIZED)

	CENTER			MID-RADIUS			OD		
PREFORM NO.	YS	RA	CVN	YS	RA	CVN	YS	RA	CVN
0271	173	33	35	170	27	30 30	173 177 171	36 51 56	33 34
0272	169	18	30	171	44	29 31	171 174 174	52 55 54	30 32
0283	173	15	26	172	33	24 26	174 176 176	39 46 45	23 28
0284	170	31	27	171	40	24 23	171 173 174	45 48 50	23 27
0323	169	27	29	(4)	(4)	29 26	158 172 173	(4) (4) 49	29 28
0324	169	29	24	169	47	23 24	171 176 173	48 50 51	24 25

(4)- Cracked test bar

FIG. 1

SPECIMEN LAYOUT

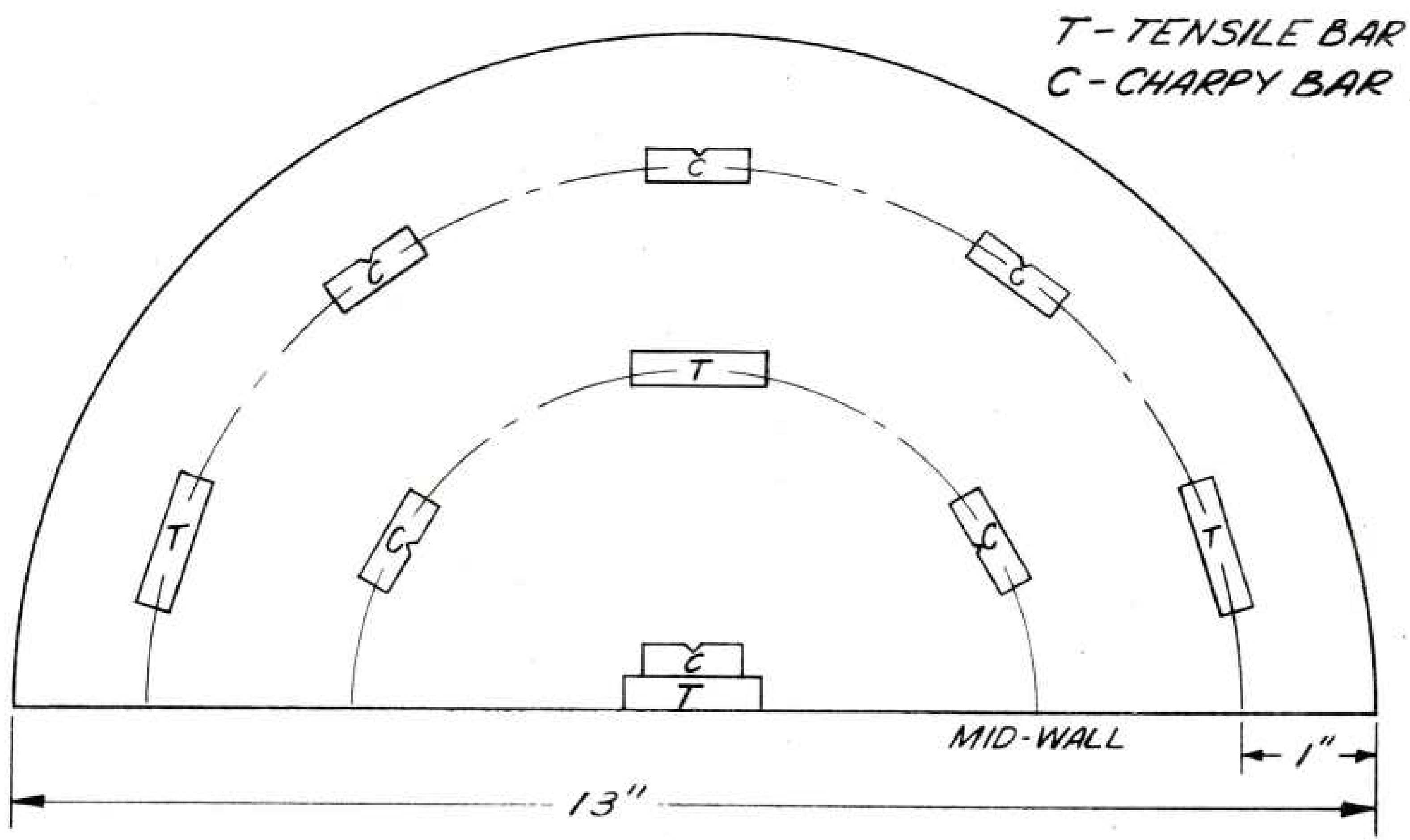


FIG. 2

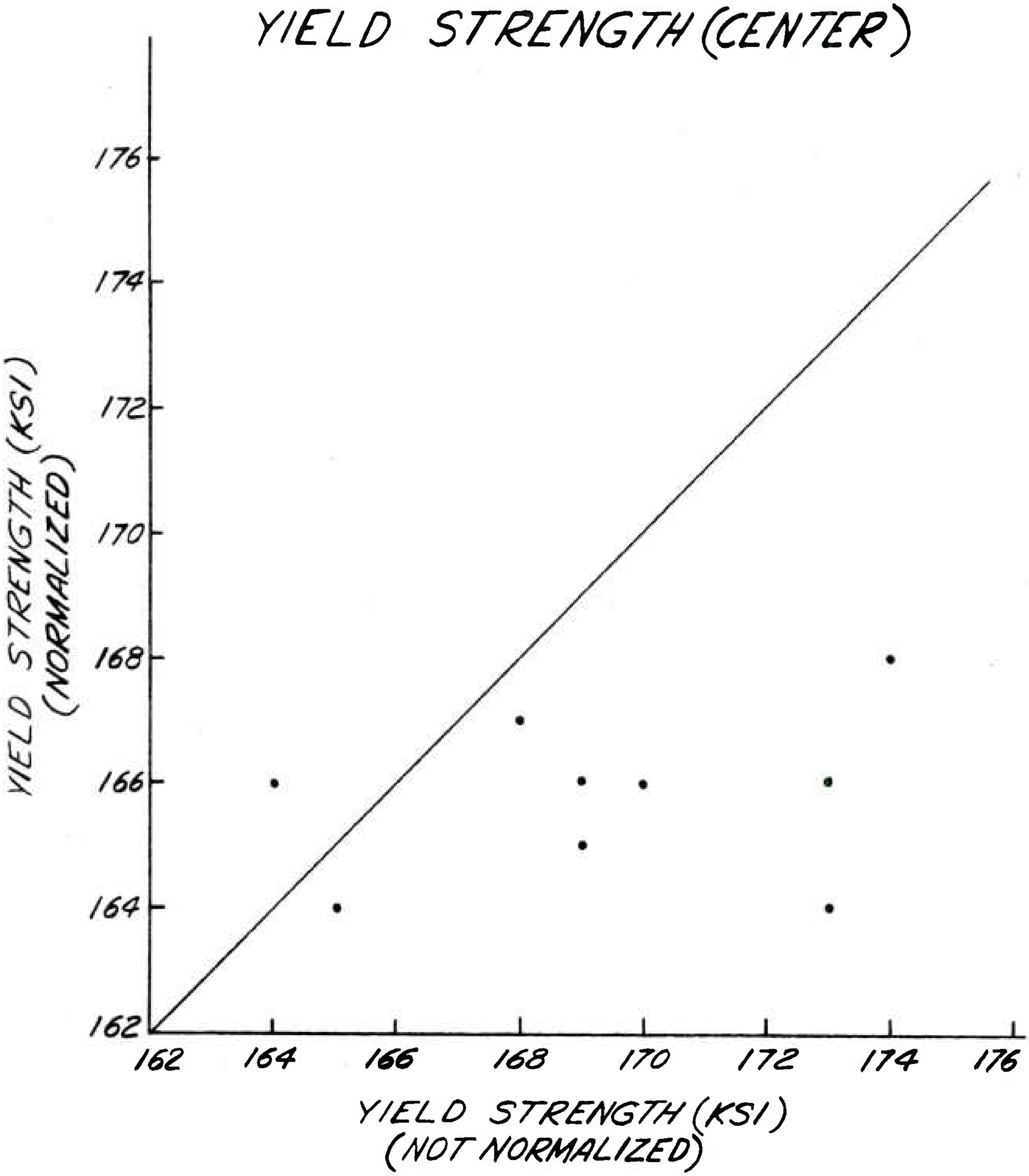

YIELD STRENGTH (CENTER)
176
174
172
170
168
166
164
162
YIELD STRENGTH (KSI)
(NORMALIZED)
162
164
166
168
170
172
174
176
YIELD STRENGTH (KSI)
(NOT NORMALIZED)

FIG. 3

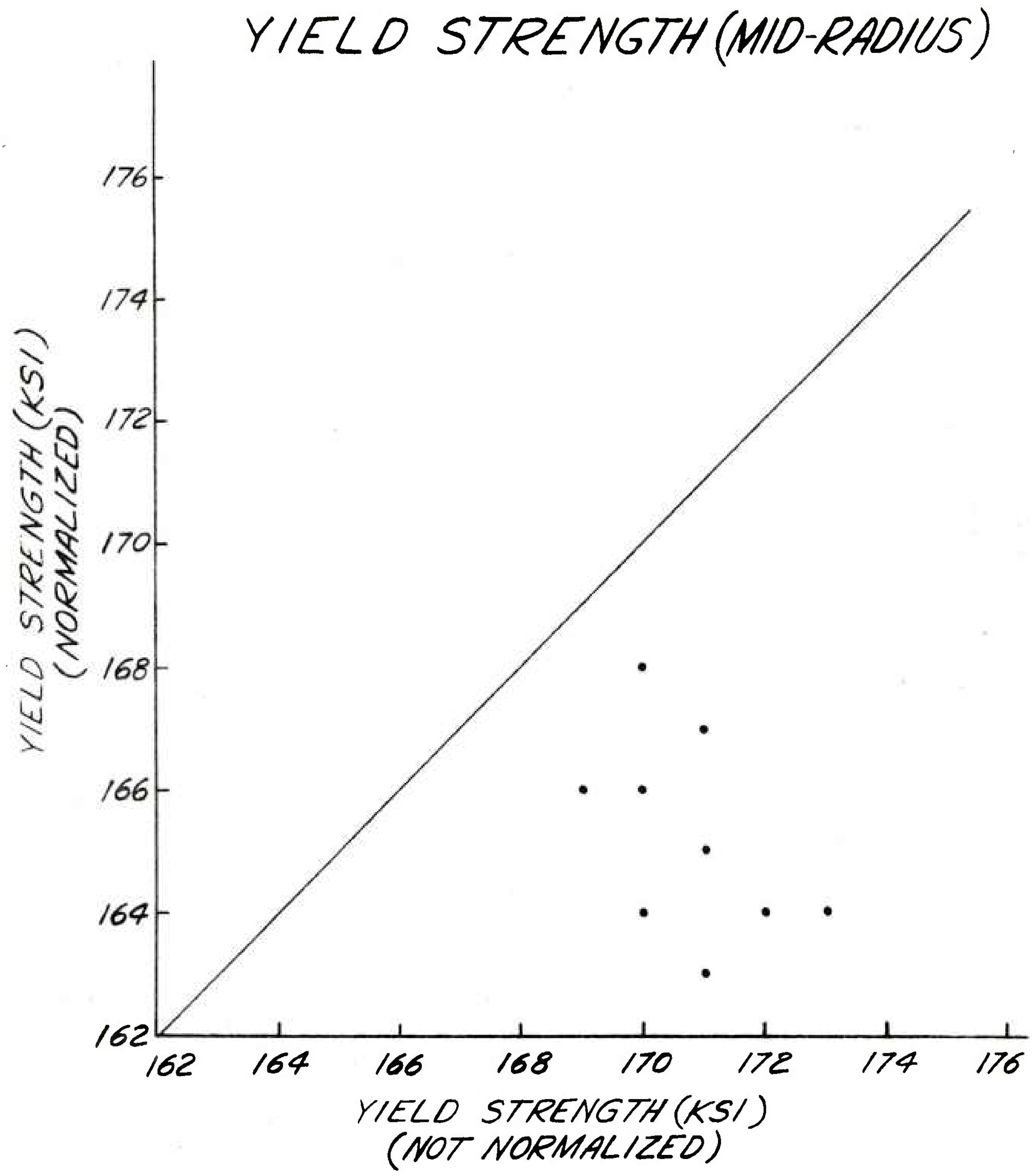
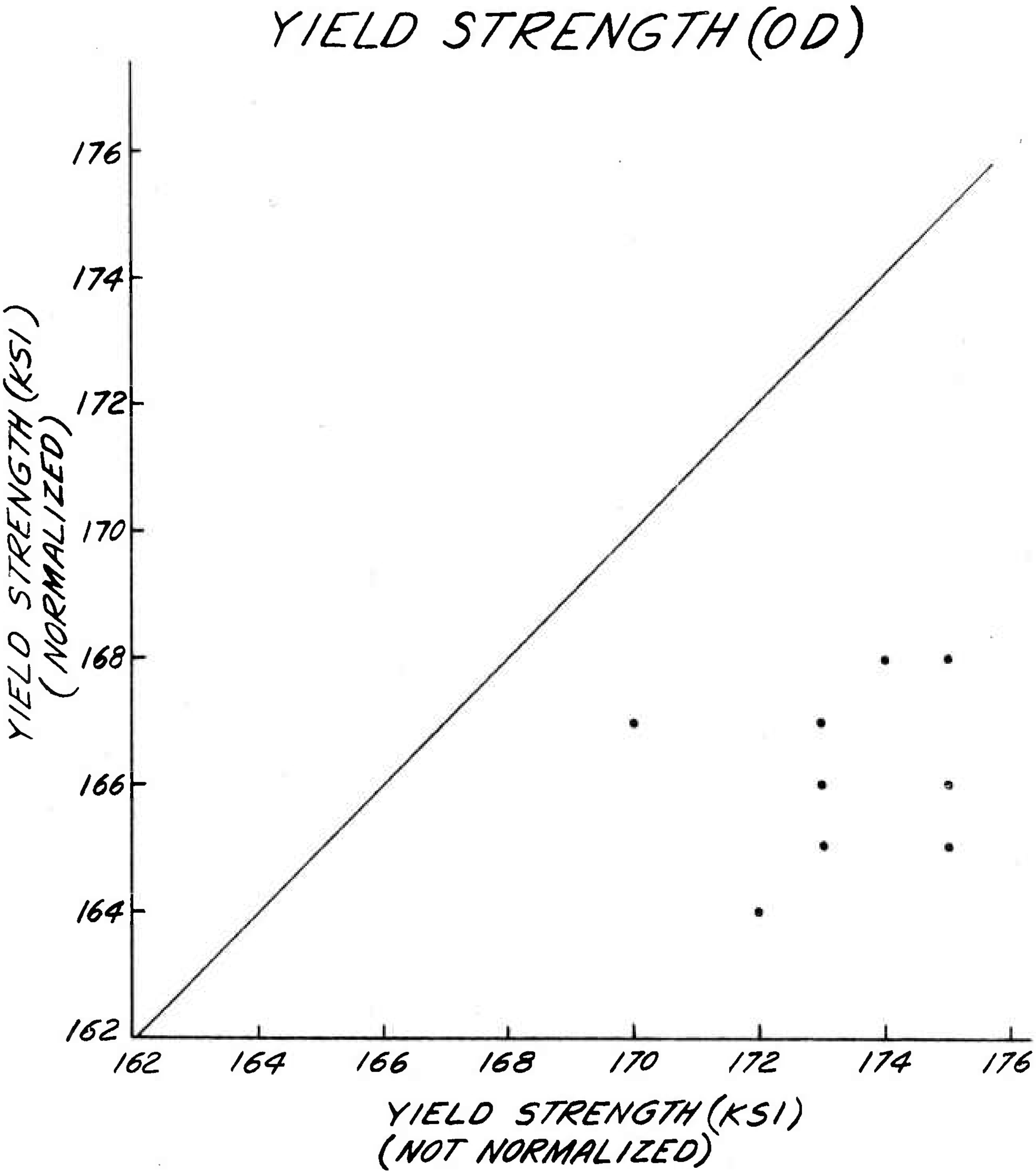

YIELD STRENGTH (MID-RADIUS)
YIELD STRENGTH (KSI)
(NORMALIZED)
176
174
172
170
168
166
164
162
162
164
166
168
170
172
174
176
YIELD STRENGTH (KSI)
(NOT NORMALIZED)

FIG. 4



YIELD STRENGTH (OD)
176
174
172
170
168
166
164
162
YIELD STRENGTH (KSI) (NORMALIZED)
162
164
166
168
170
172
174
176
YIELD STRENGTH (KSI) (NOT NORMALIZED)

FIG. 5

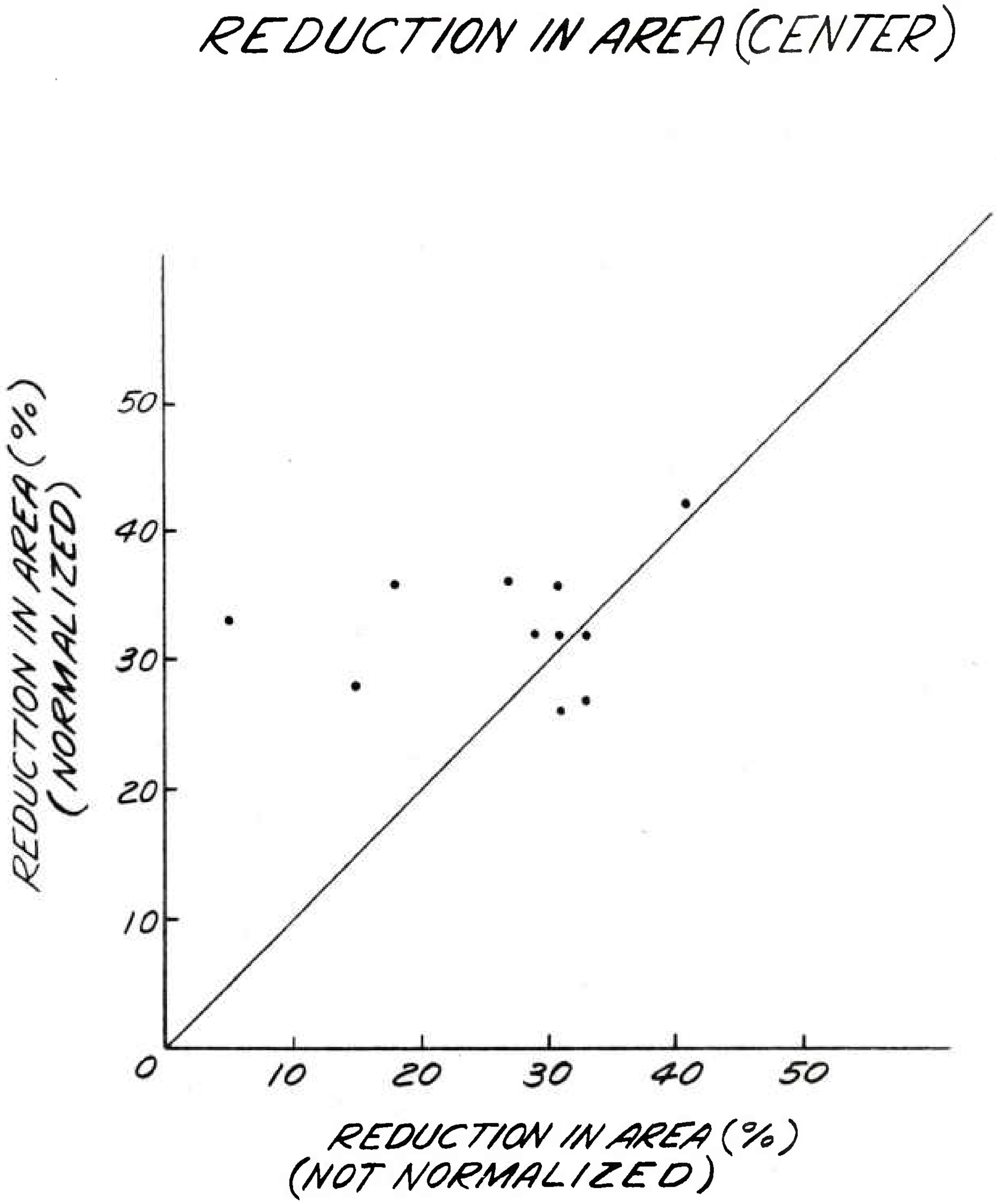

REDUCTION IN AREA (CENTER)
REDUCTION IN AREA (%)
(NORMALIZED)
50
40
30
20
10
0
10
20
30
40
50
REDUCTION IN AREA (%)
(NOT NORMALIZED)

FIG. 6

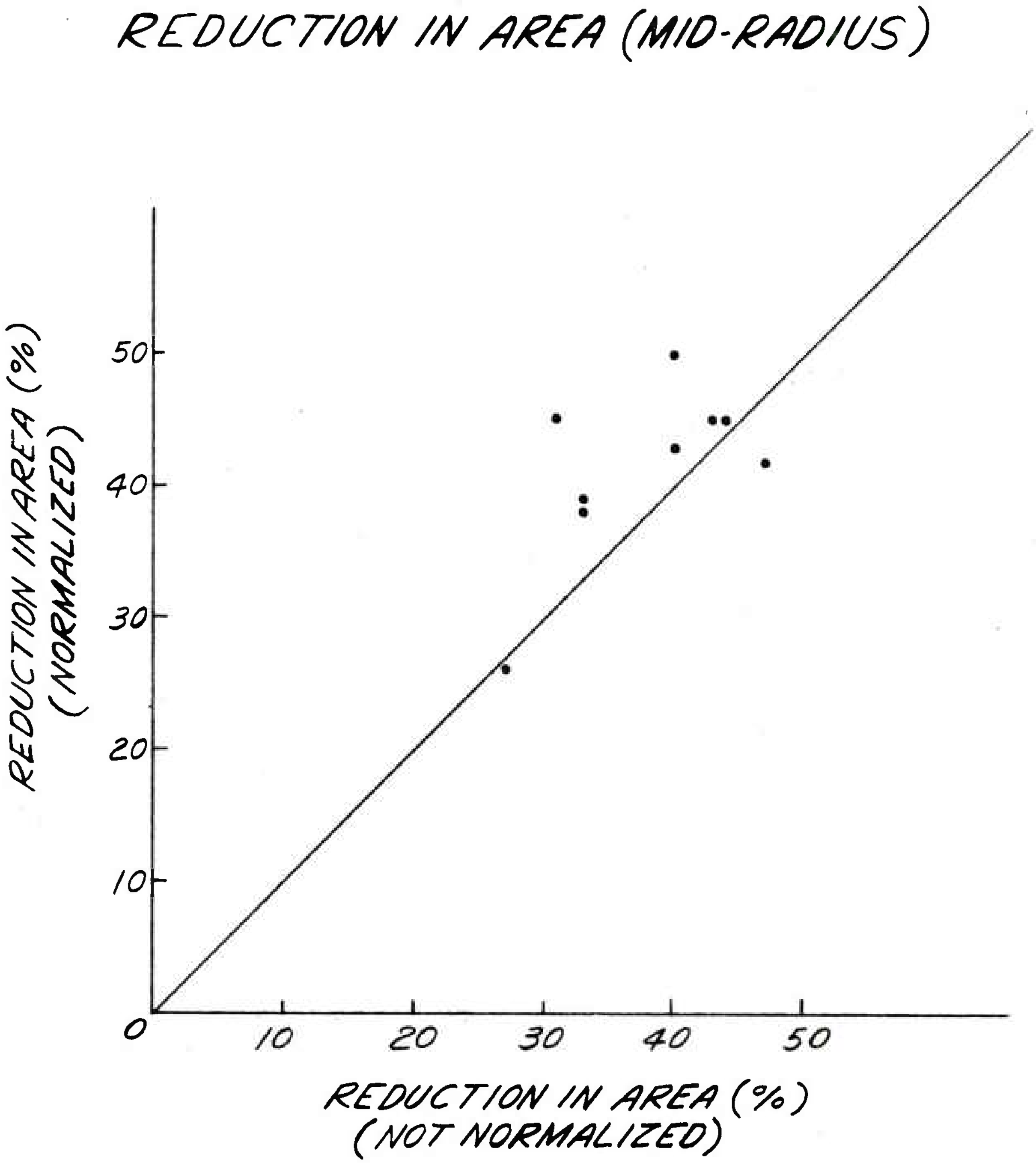

REDUCTION IN AREA (MID-RADIUS)
REDUCTION IN AREA (%)
(NORMALIZED)
50
40
30
20
10
0
10
20
30
40
50
REDUCTION IN AREA (%)
(NOT NORMALIZED)

FIG. 7

REDUCTION IN AREA (OD)

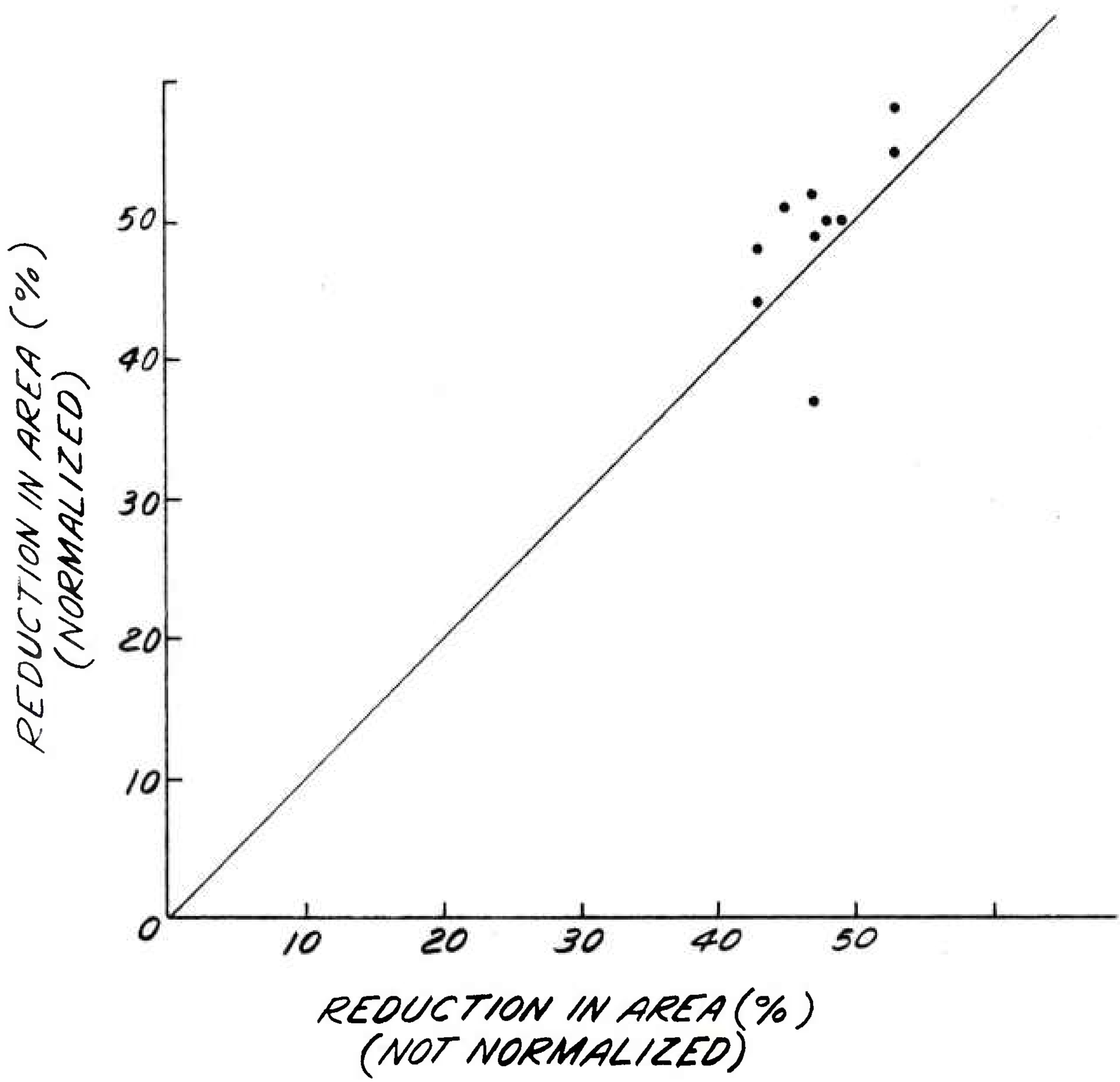
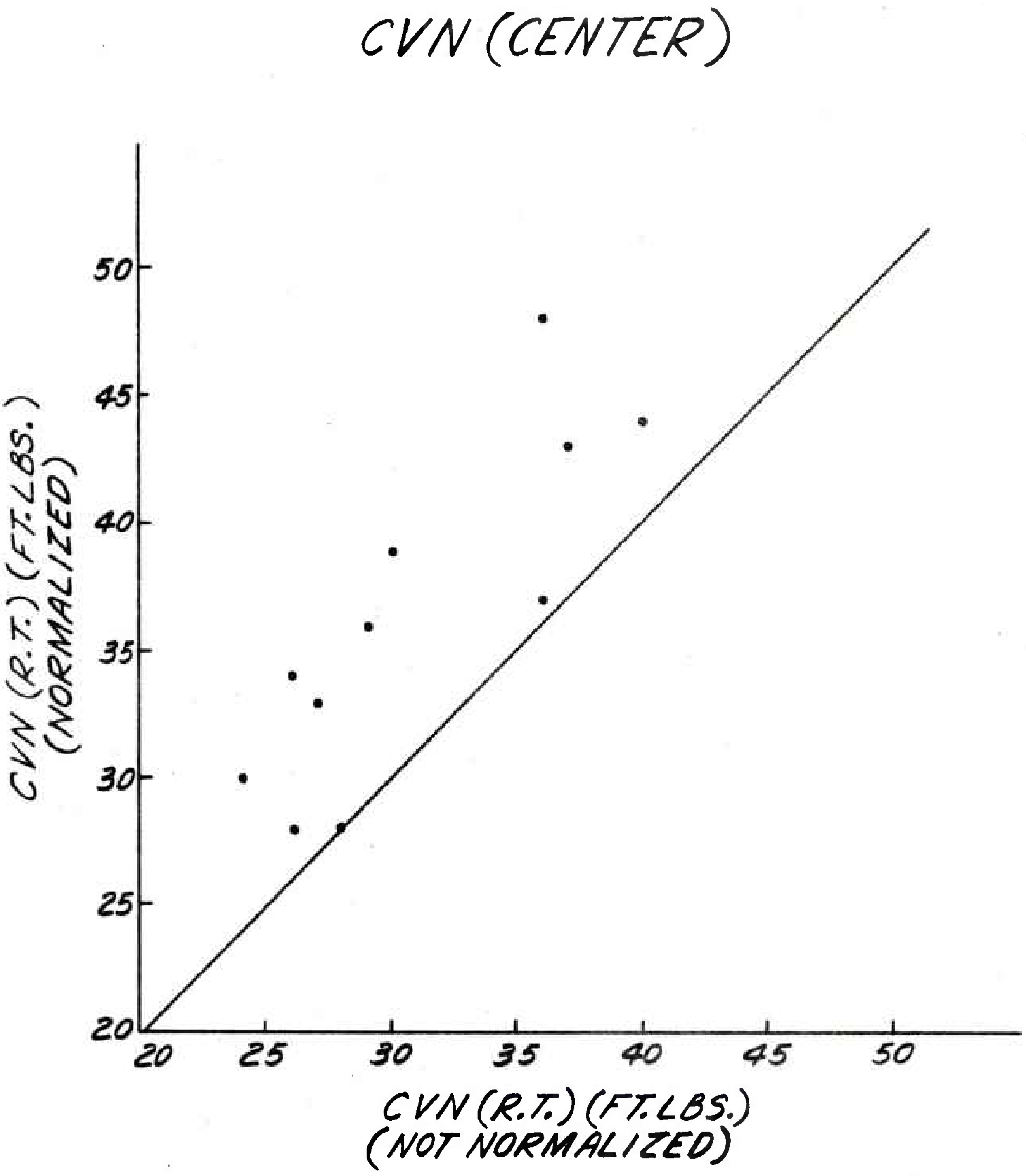


FIG. 8



CVN (CENTER)
CVN (R.T.) (FT.LBS.)
(NORMALIZED)
50
45
40
35
30
25
20
20
25
30
35
40
45
50
CVN (R.T.) (FT.LBS.)
(NOT NORMALIZED)

FIG. 9

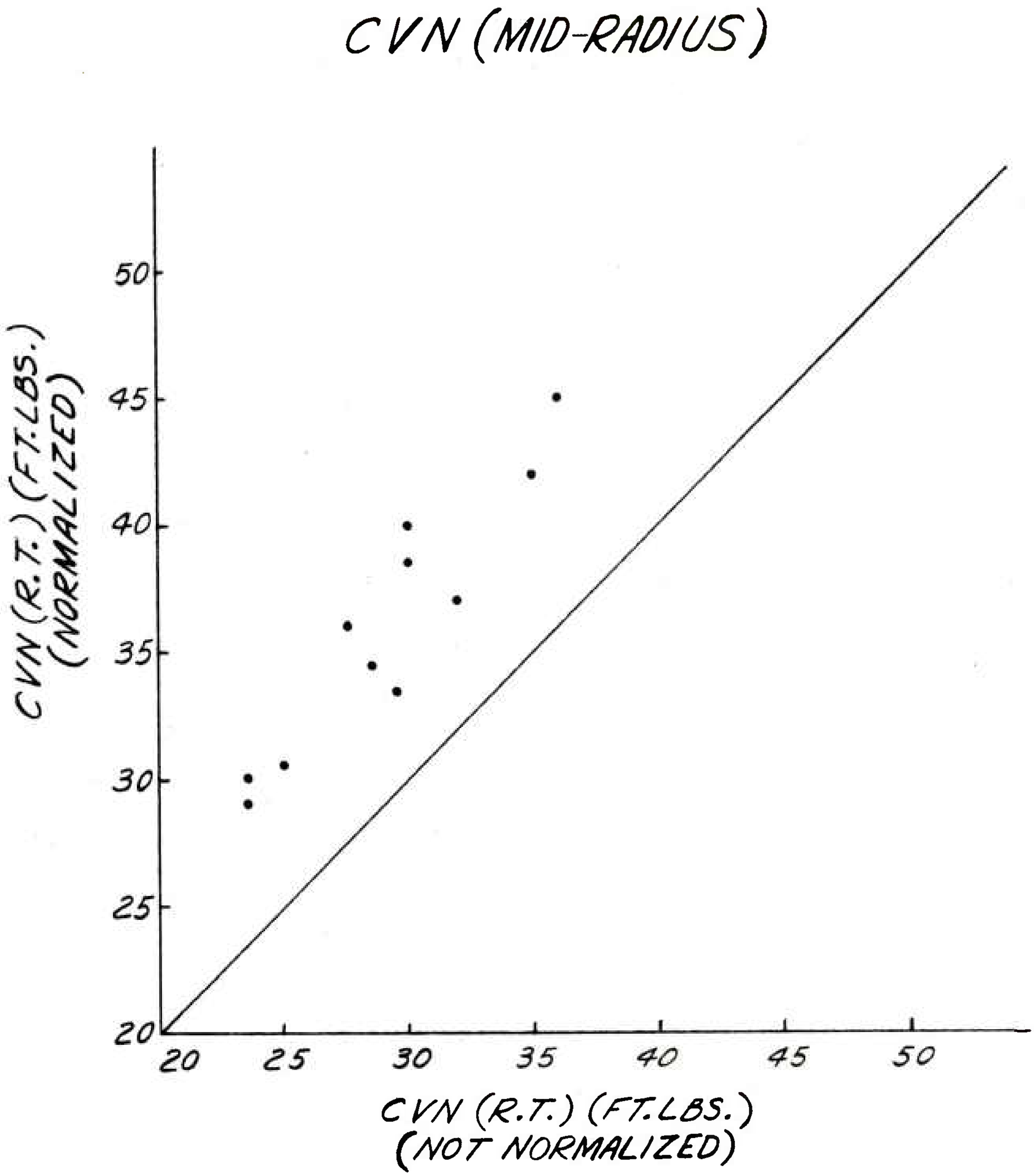

CVN (MID-RADIUS)
CVN (R.T.) (FT.LBS.) (NORMALIZED)
20
25
30
35
40
45
50
CVN (R.T.) (FT.LBS.) (NOT NORMALIZED)

FIG. 10

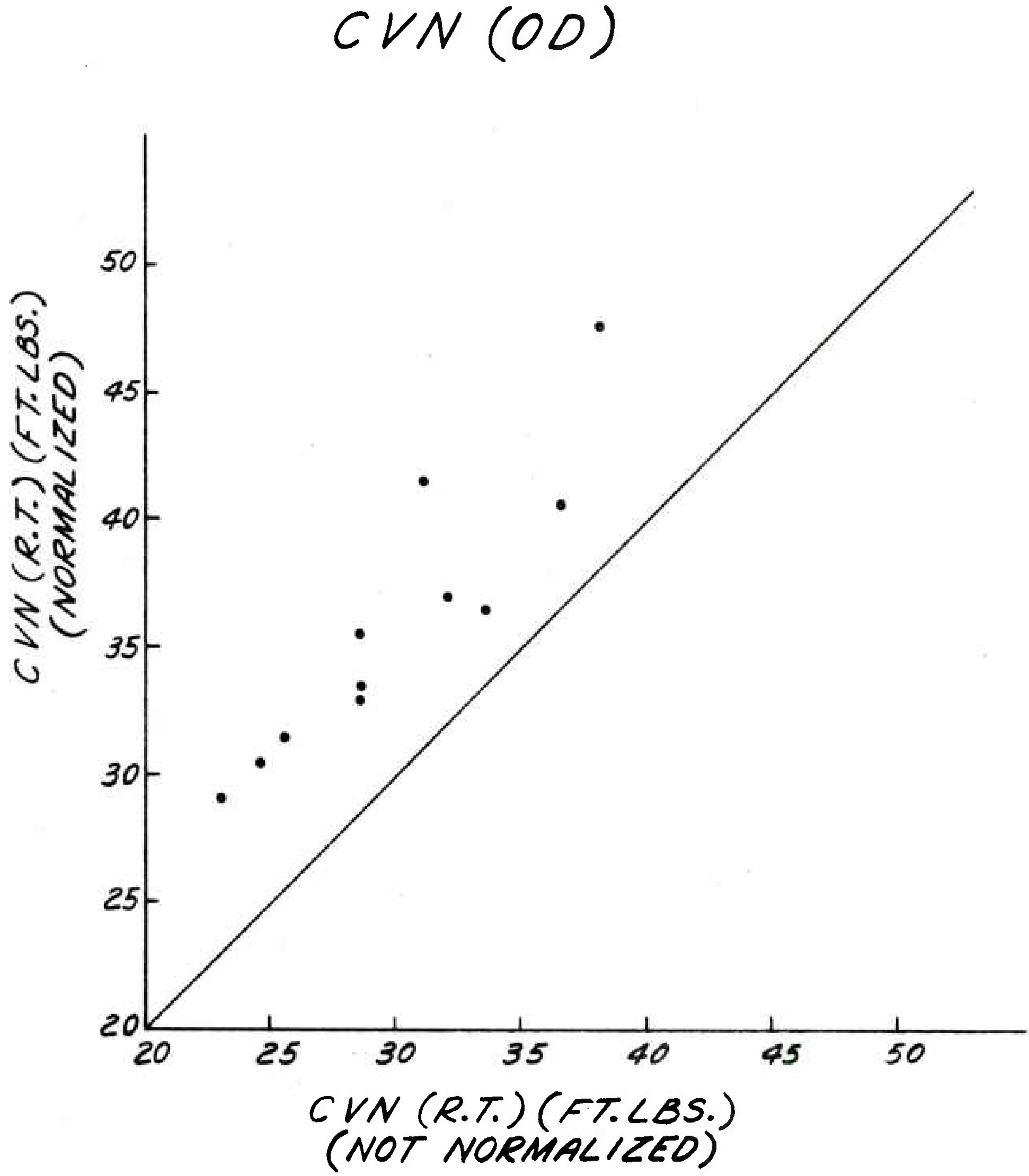

CVN (OD)
50
45
40
35
30
25
20
CVN (R.T.) (FT.LBS.) (NORMALIZED)
20
25
30
35
40
45
50
CVN (R.T.) (FT.LBS.) (NOT NORMALIZED)

FIG. 11a - 0260 - Center
20X - Residual Dendritic Structure
(Not Normalized)

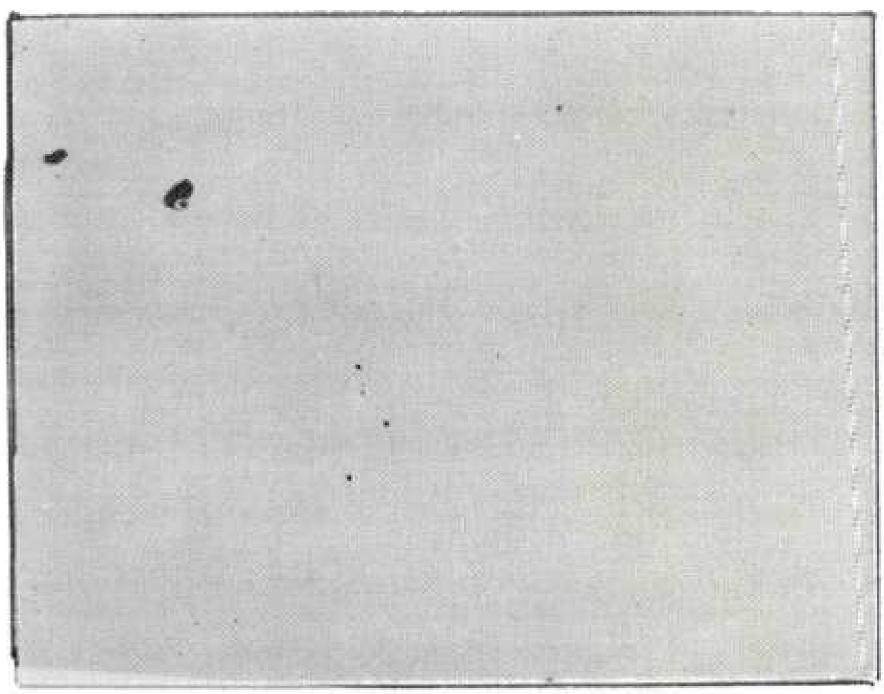


FIG. 11b - 0260 - Center
100X - Inclusion Pattern
(Not Normalized)

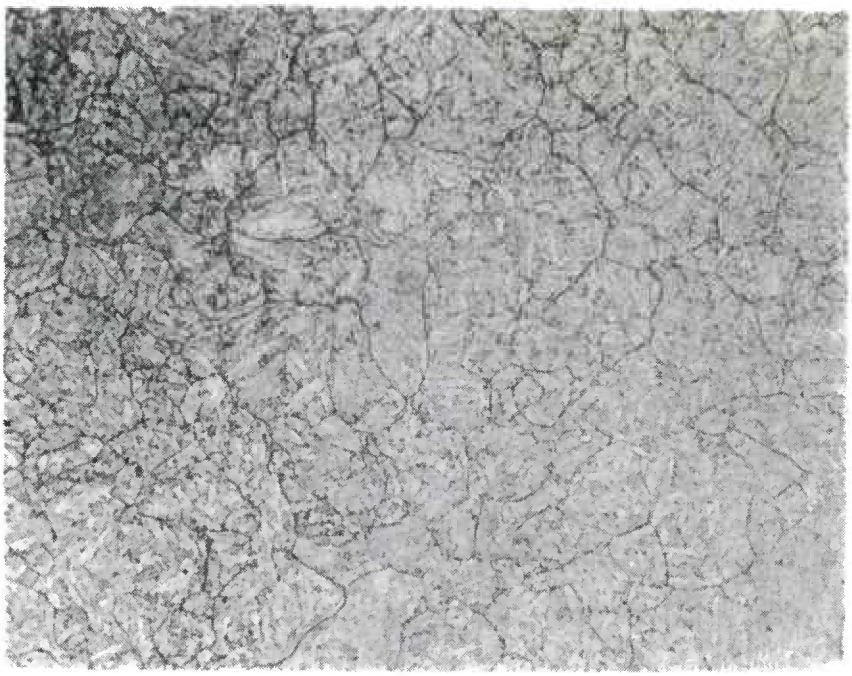


FIG. 11c - 0260 - Center
500X - Tempered Martensite
(Not Normalized)

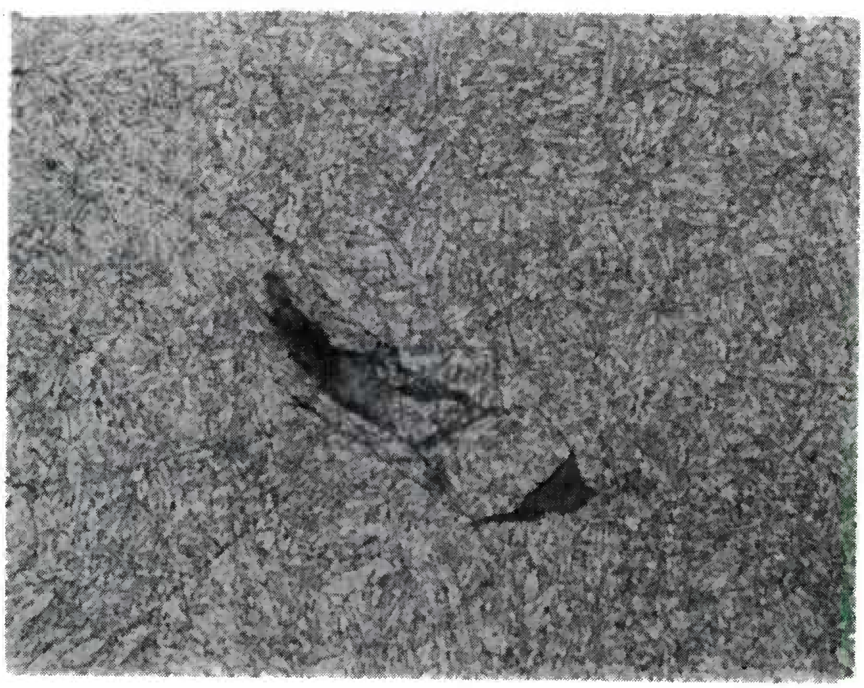


FIG. 11d - 0260 - Center
1000X - Tempered Martensite
(Not Normalized)

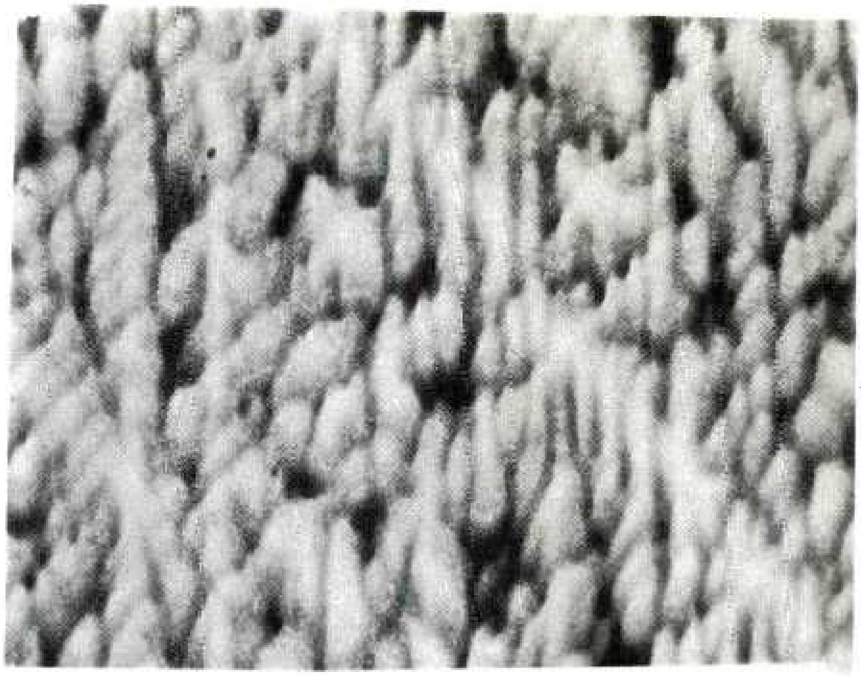


FIG. 12a - 0250 - Center
20X - Residual Dendritic Structure
(Normalized)

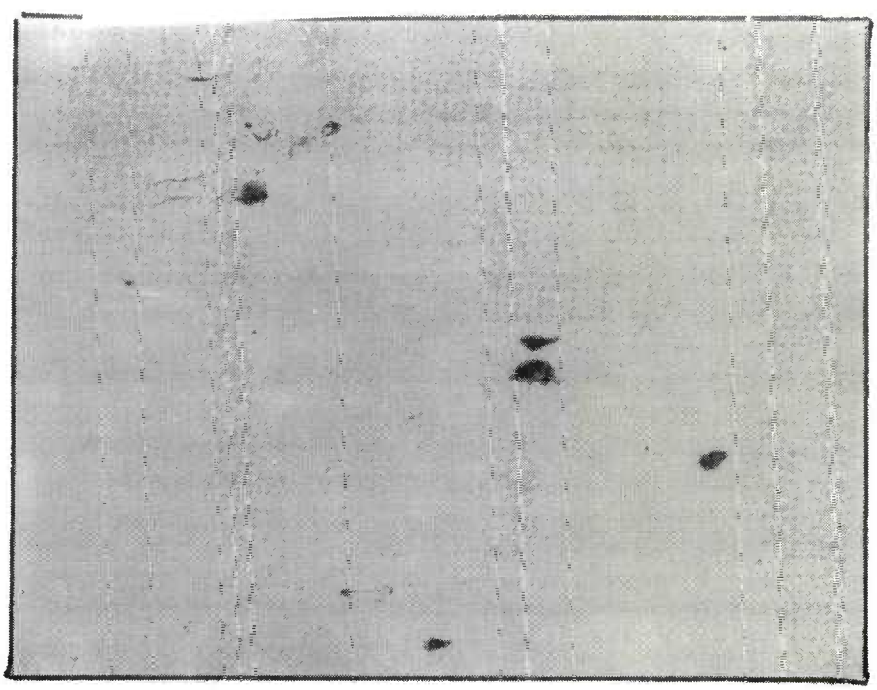


FIG. 12b - 0260 - Center
100X - Inclusion Pattern
(Normalized)

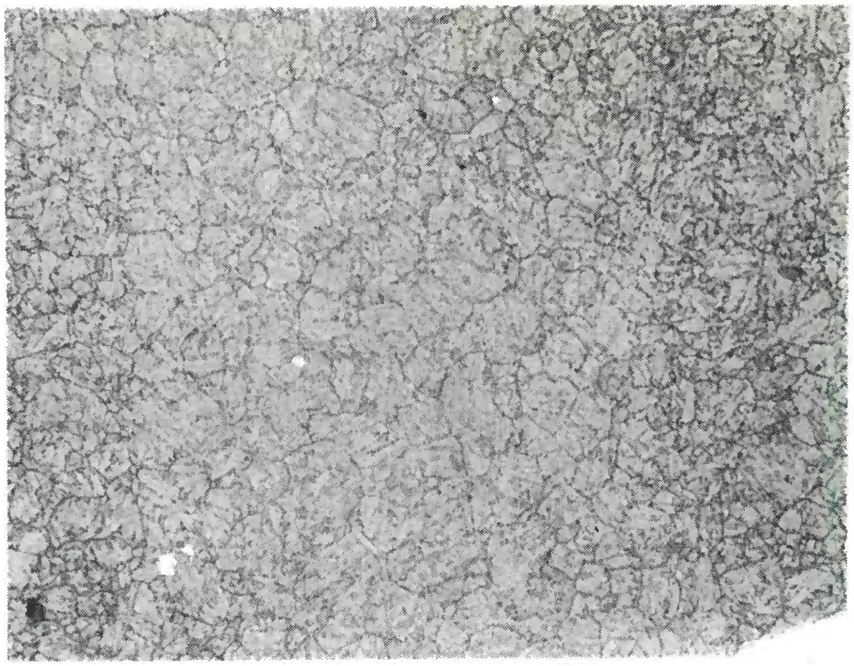


FIG. 12c - 0260 - Center
500X - Tempered Martensite
(Normalized)

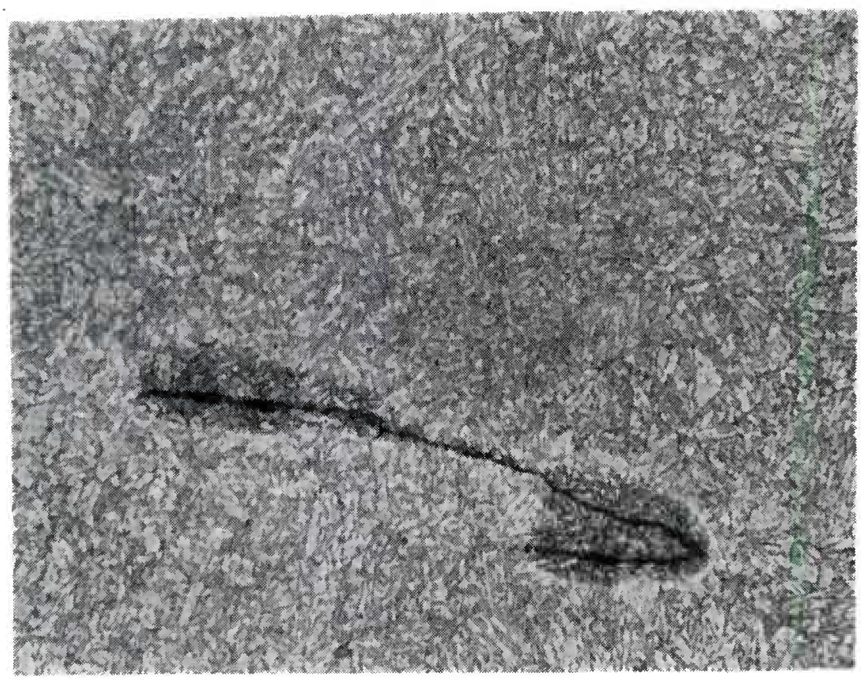


FIG. 12d - 0260 - Center
1000X - Tempered Martensite
(Normalized)

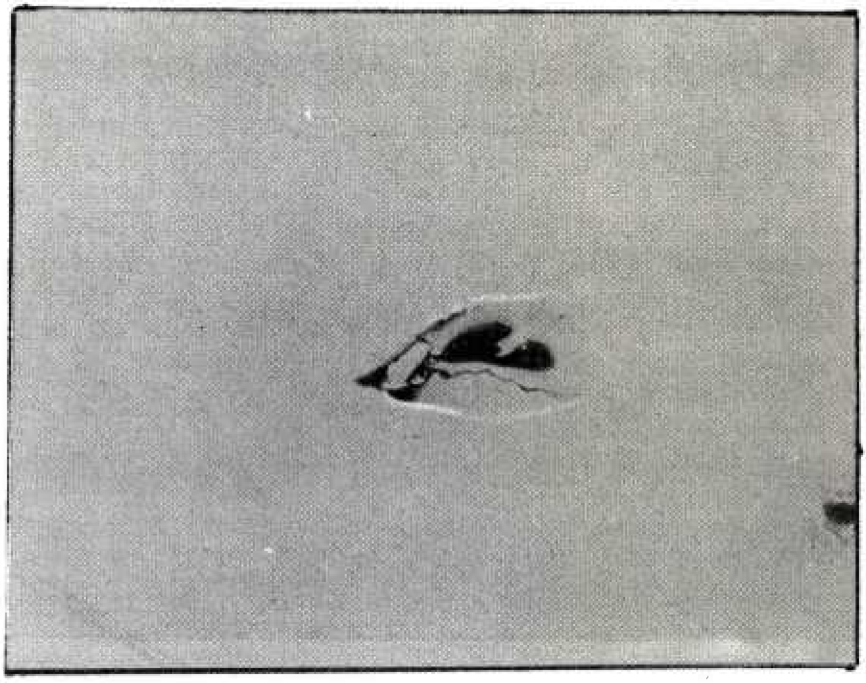


FIG. 12e - 0260 - Center
500X - Large Void
(Normalized)

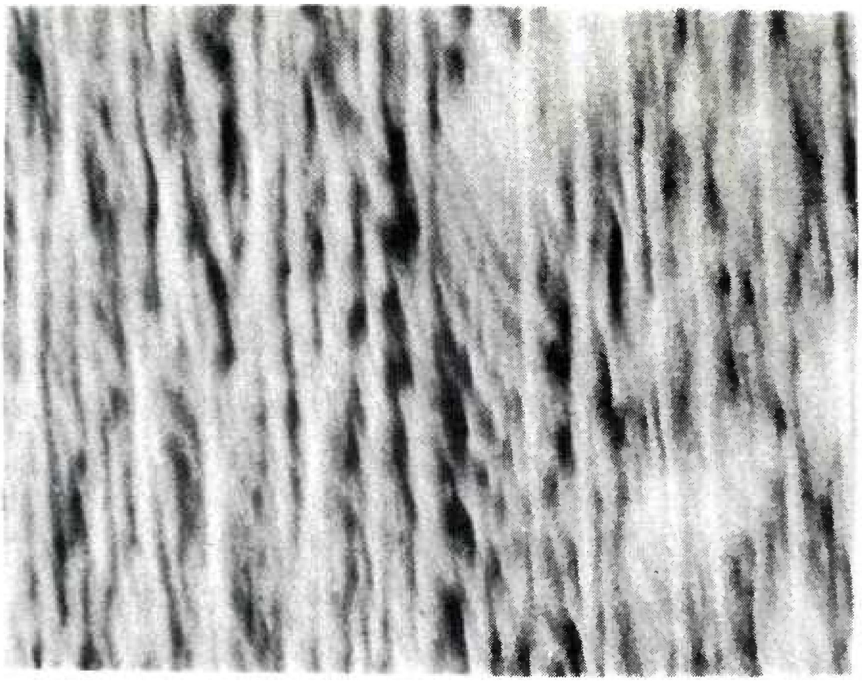


FIG. 13a - 0260 - OD
20X - Residual Dendritic Structure
(Not Normalized)

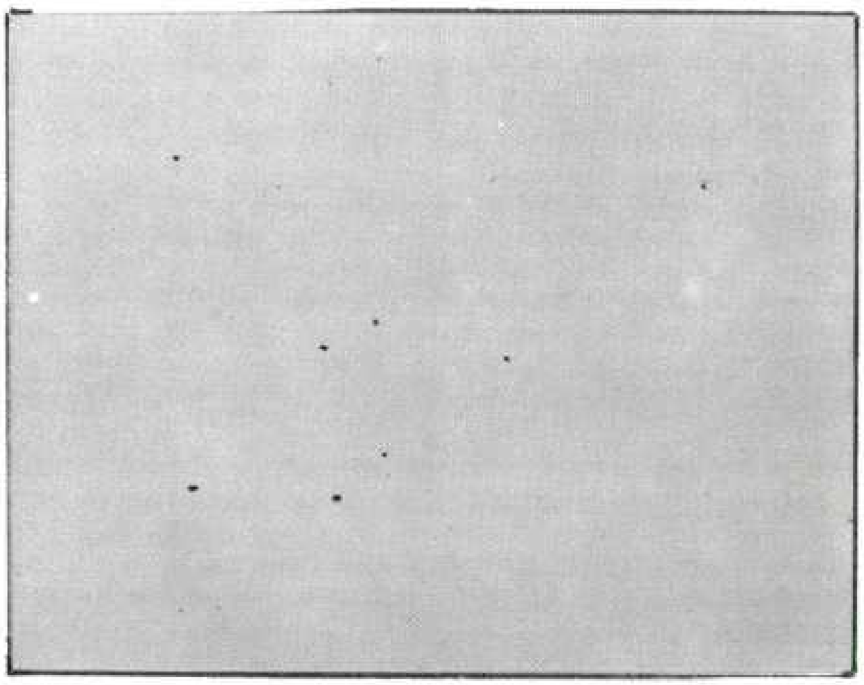


FIG. 13b - 0260 - OD
100X - Inclusion Pattern
(Not Normalized)

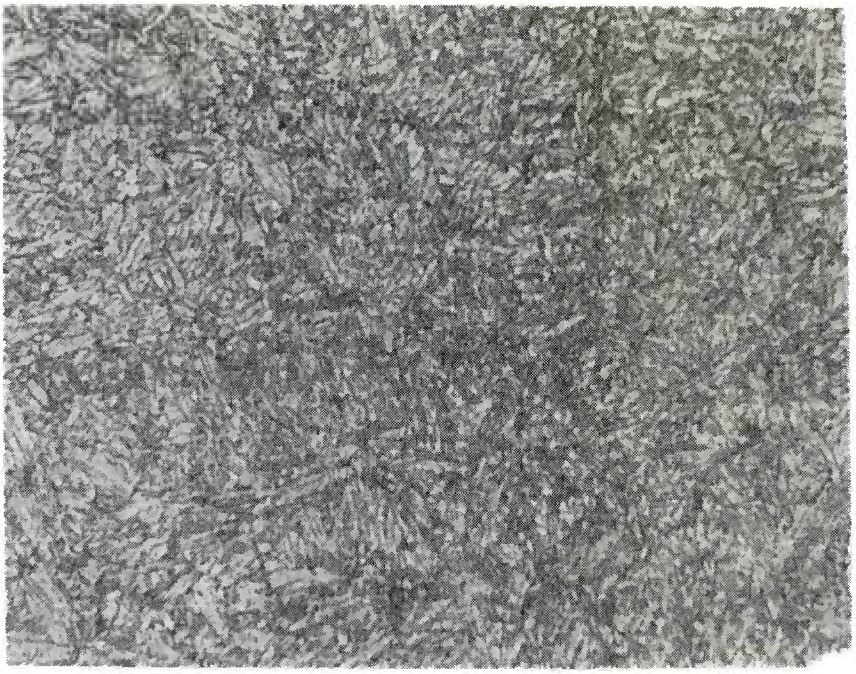


FIG. 13c - 0260 - OD
500X - Tempered Martensite
(Not Normalized)

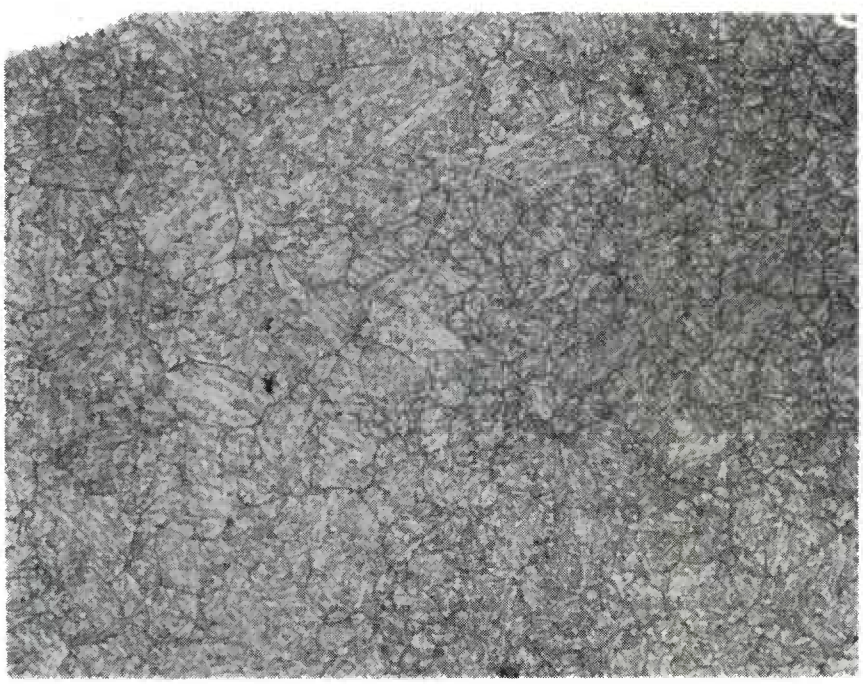


FIG. 13d - 0260 - OD
1000X - Tempered Martensite
(Not Normalized)

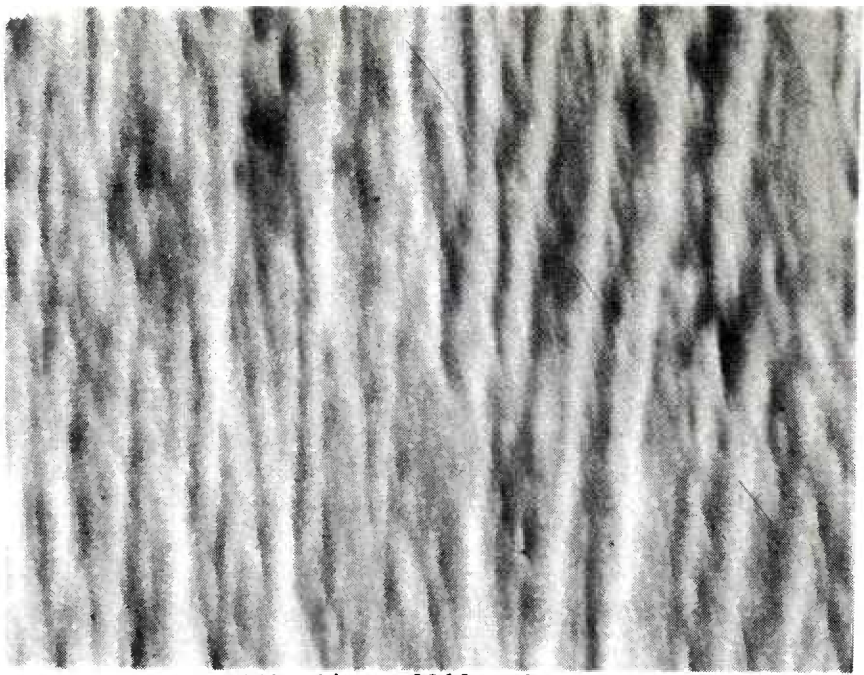


FIG. 14a - 0260 - OD
20X - Residual Dendritic Structure
(Normalized)

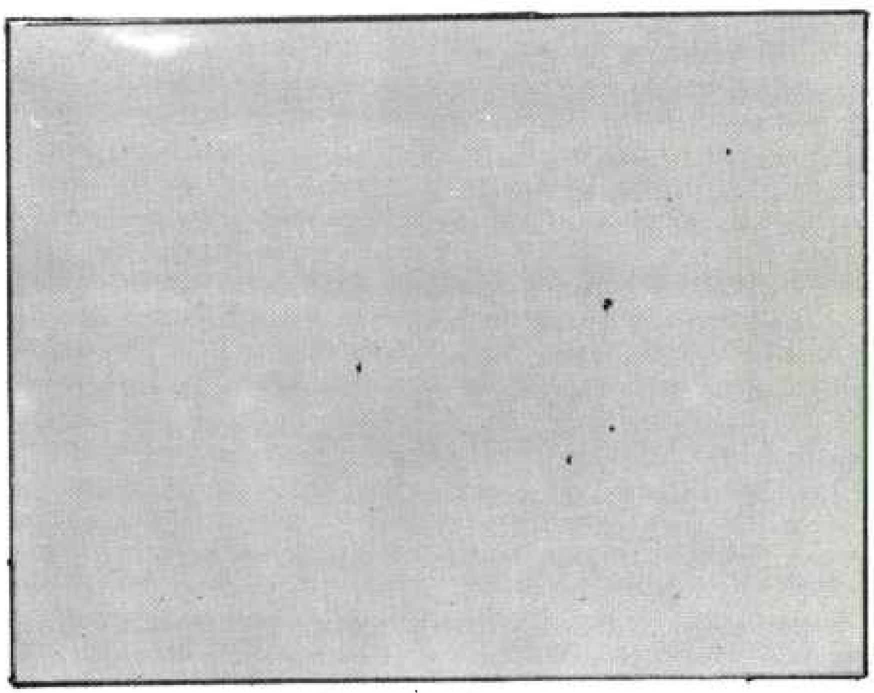


FIG. 14b - 0260 - OD
100X - Inclusion Pattern
(Normalized)

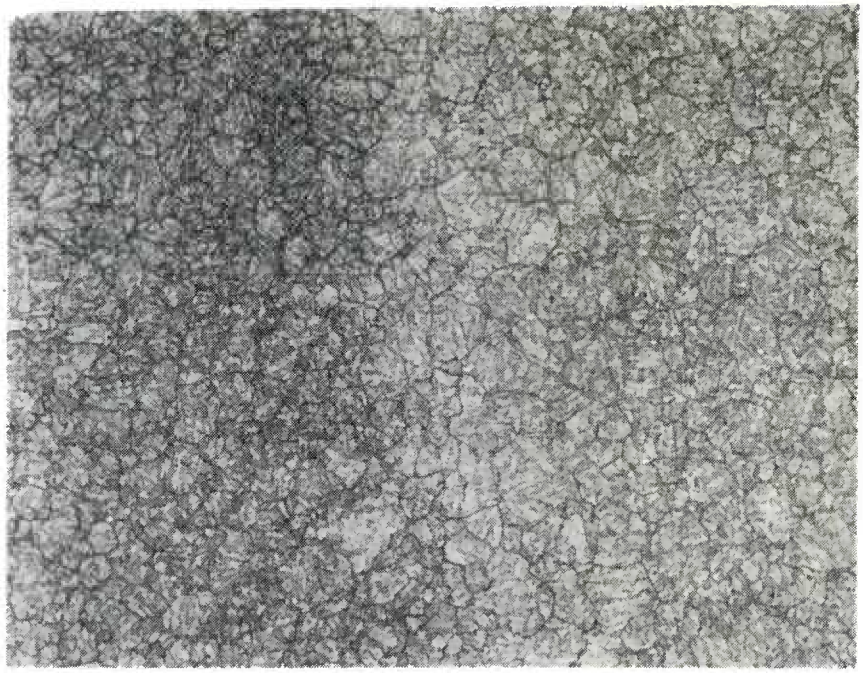


FIG. 14c - 0260 - OD
500X - Tempered Martensite
(Normalized)

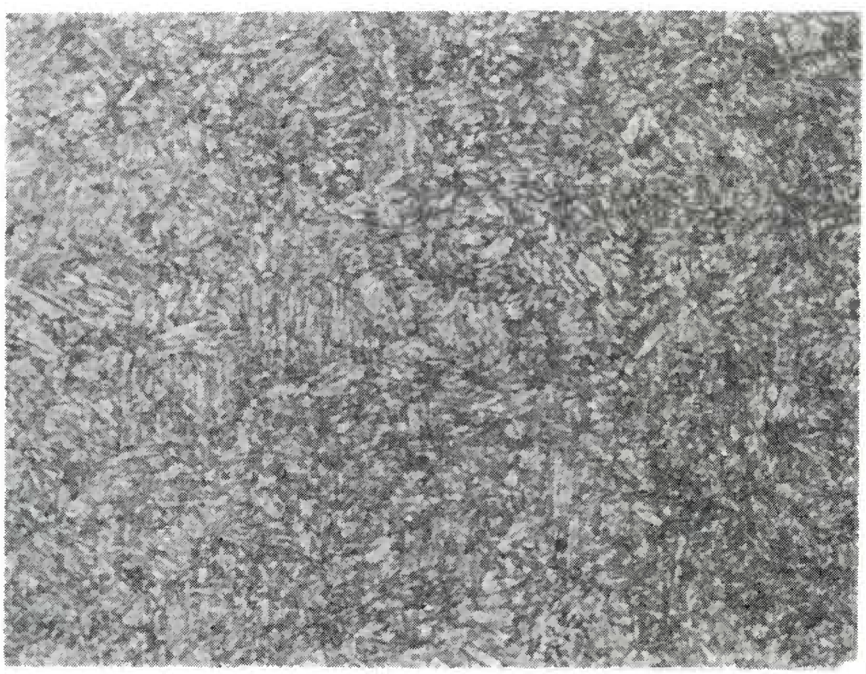


FIG. 14d - 0260 - OD
1000X - Tempered Martensite
(Normalized)

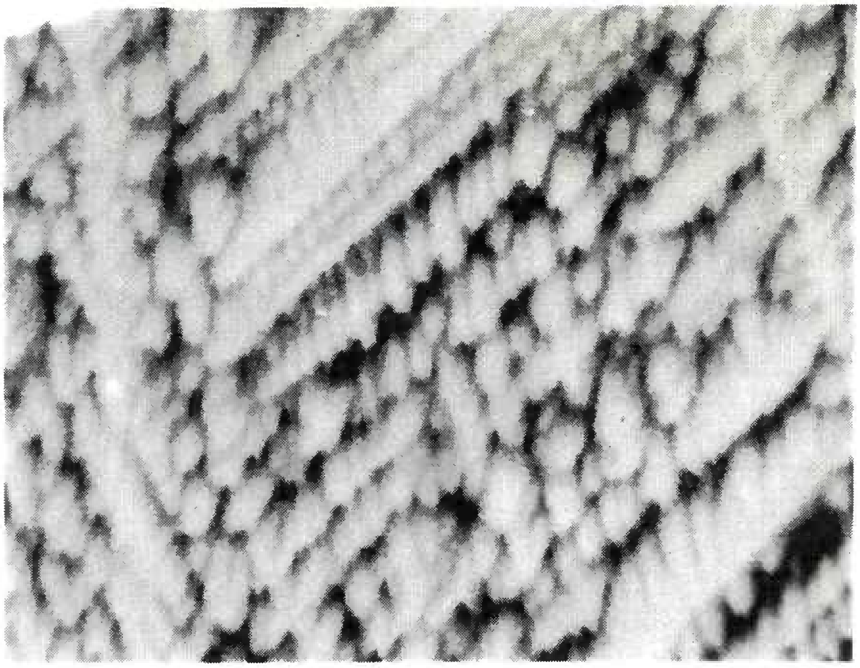


FIG. 15a - 0323 - Center
20X - Residual Dendritic Structure
(Not Normalized)

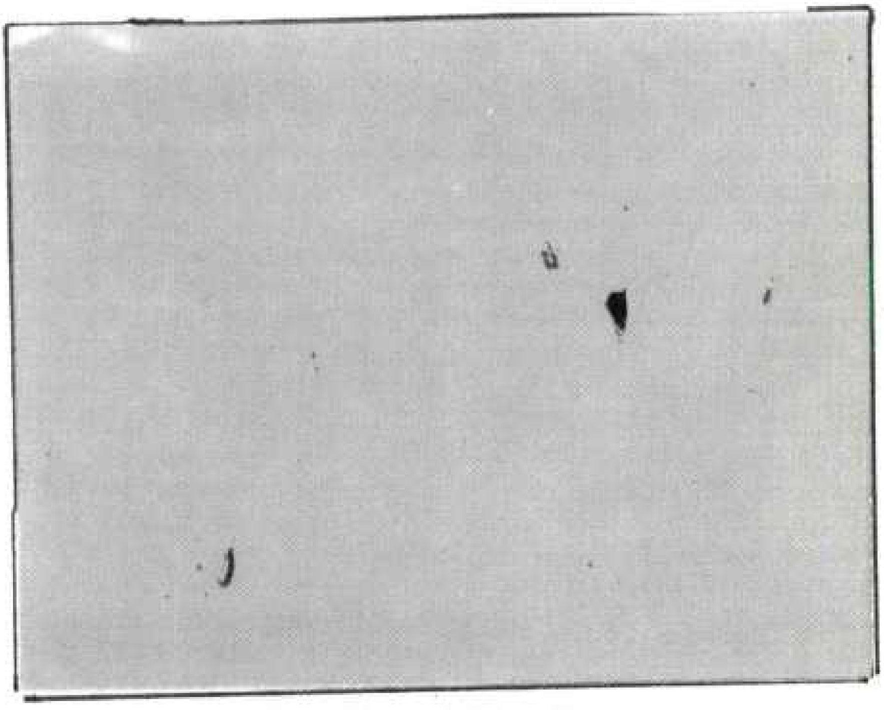


FIG. 15b - 0323 - Center
100X - Inclusion Pattern
(Not Normalized)

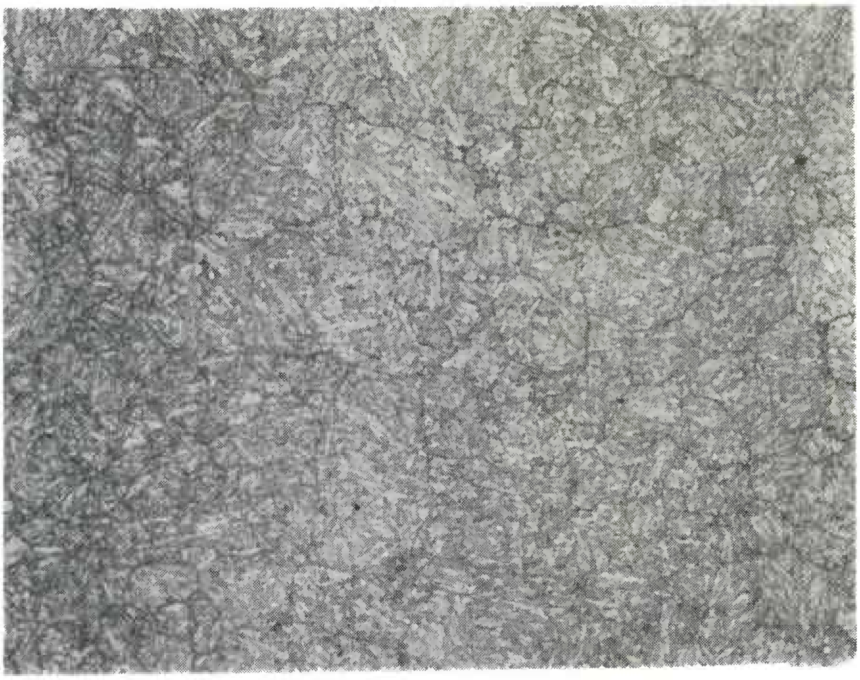


FIG. 15c - 0323 - Center
500X - Tempered Martensite
(Not Normalized)

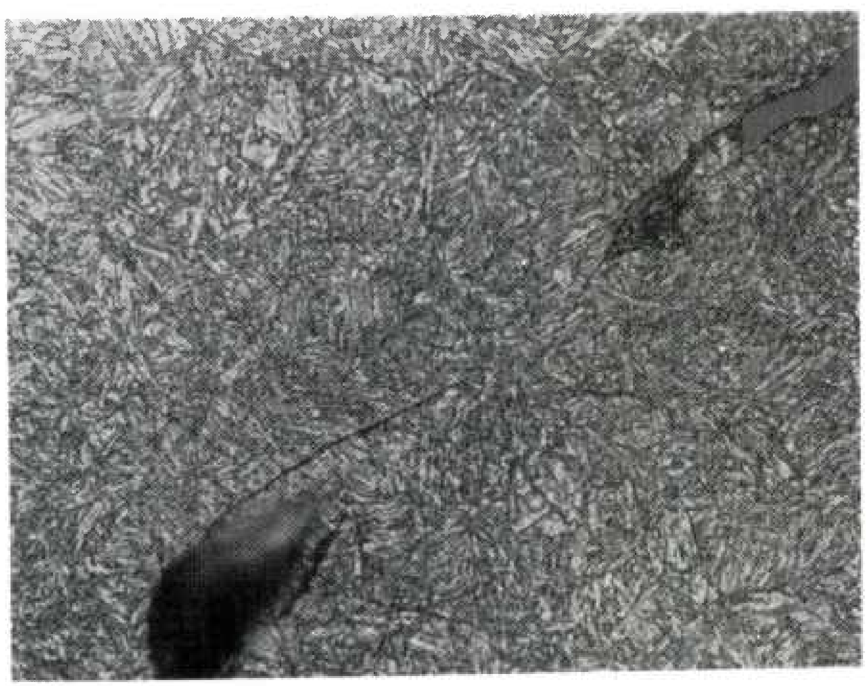


FIG. 15d - 0323 - Center
1000X - Tempered Martensite
(Not Normalized)

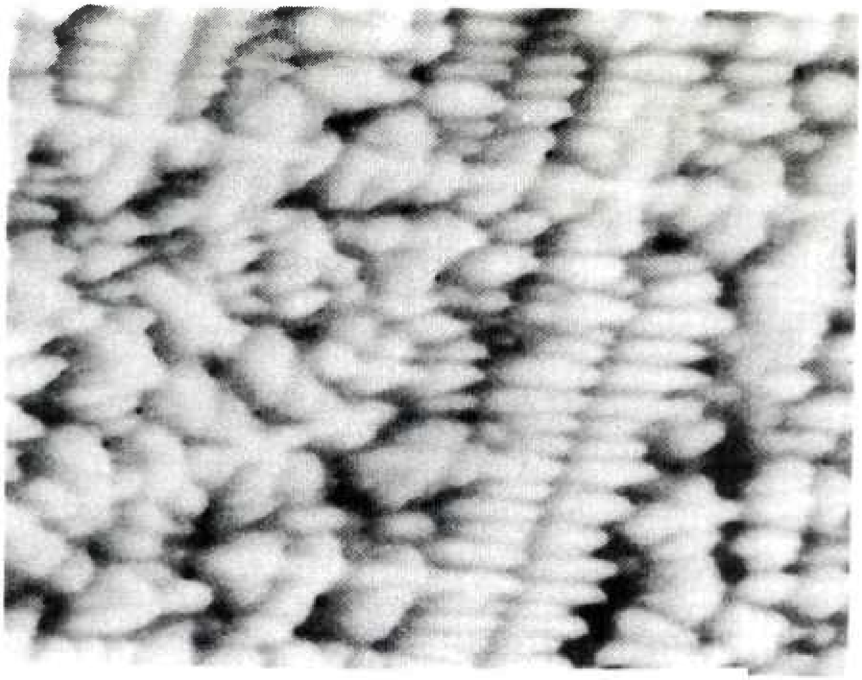


FIG. 16a - 0323 - Center
20X - Residual Dendritic Structure
(Normalized)

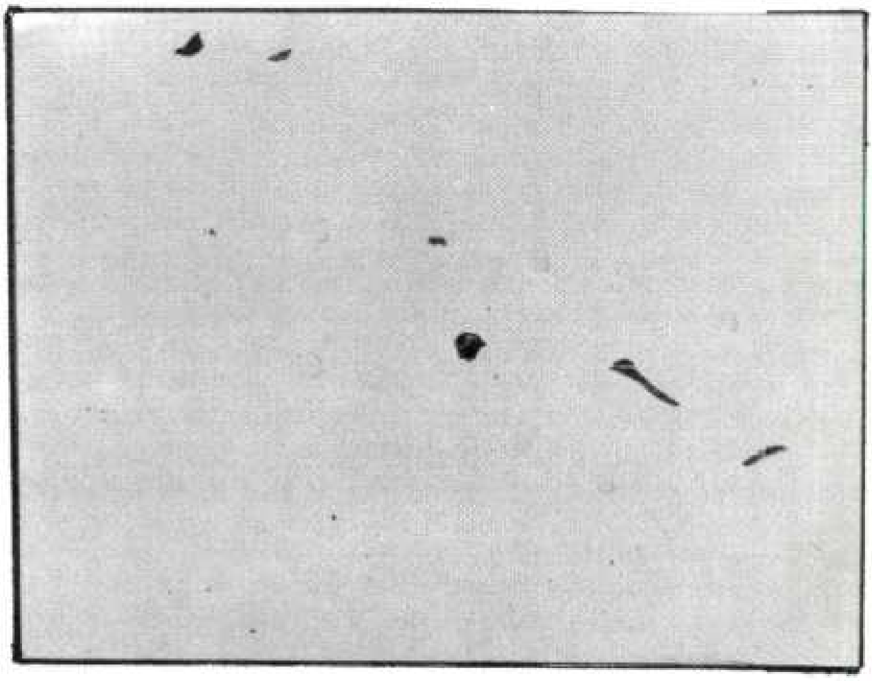


FIG. 16b - 0323 - Center
100X - Inclusion Pattern
(Normalized)

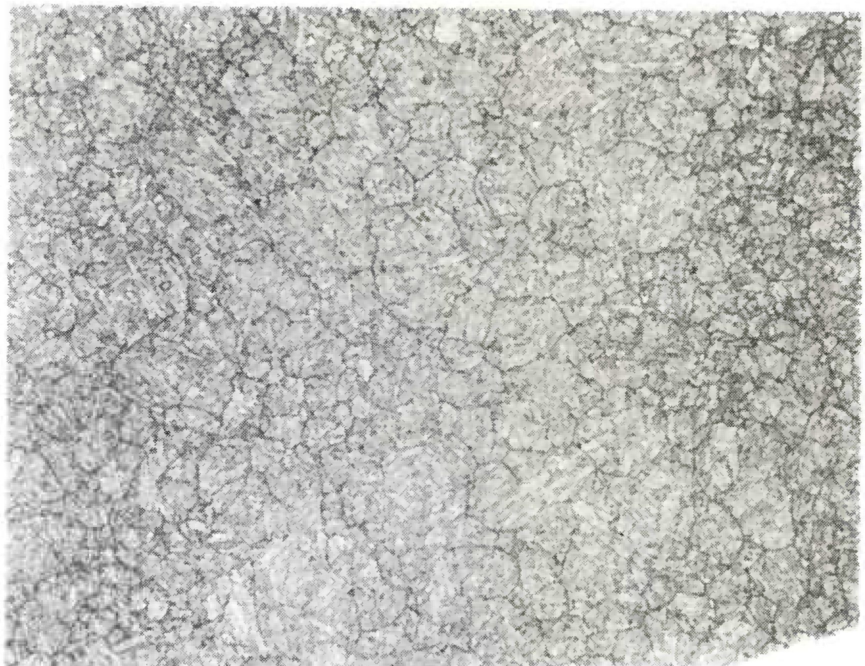


FIG. 16c - 0323 - Center
500X - Tempered Martensite
(Normalized)

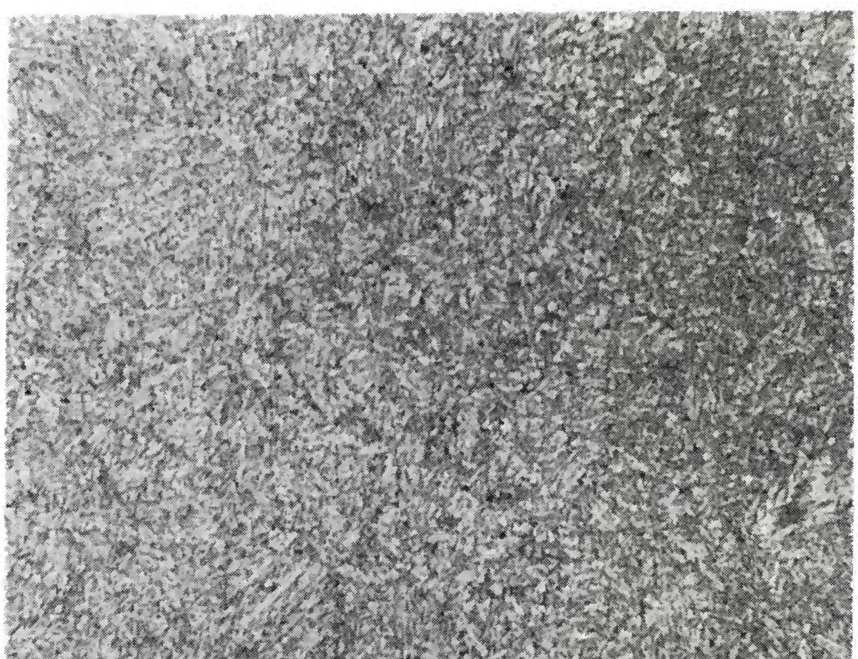


FIG. 16d - 0323 - Center
1000X - Tempered Martensite
(Normalized)

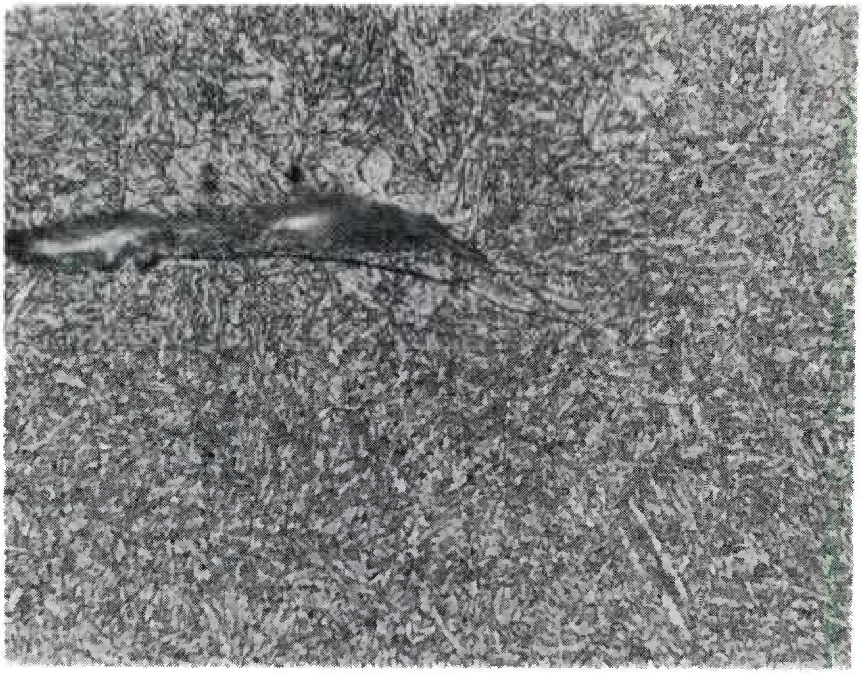


FIG. 16e - 0323 - Center
1000X - Large Inclusion
(Normalized)

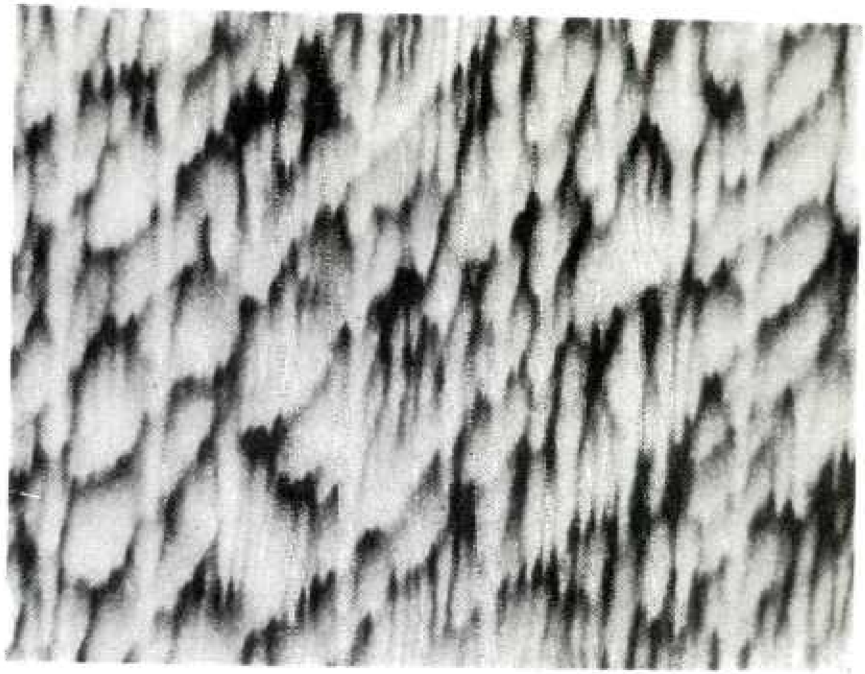


FIG. 17a - 0323 - Mid-Radius
20X - Residual Dendritic Structure
(Not Normalized)

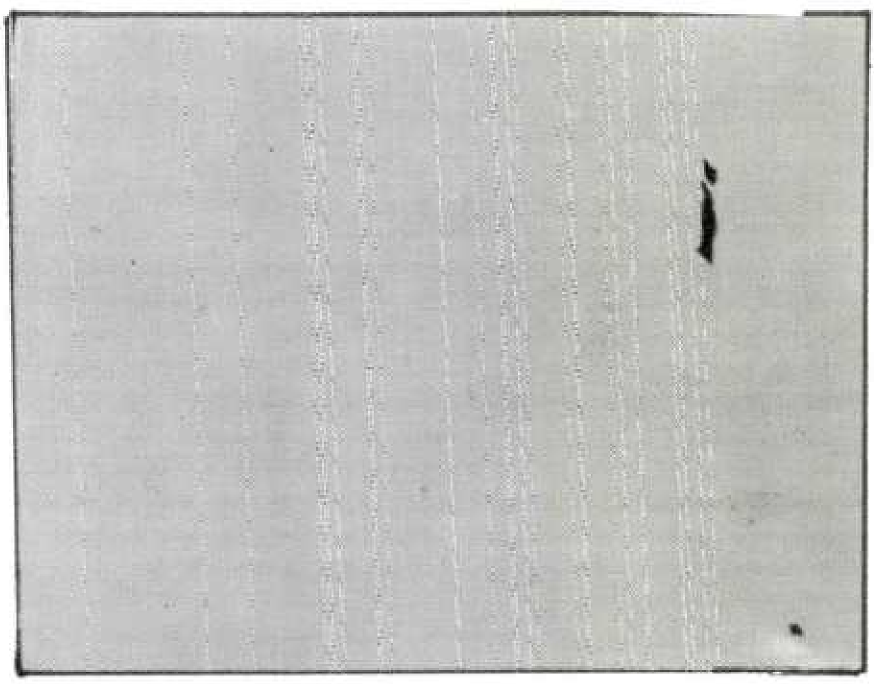


FIG. 17b - 0323 - Mid-Radius
100X - Inclusion Pattern
(Not Normalized)

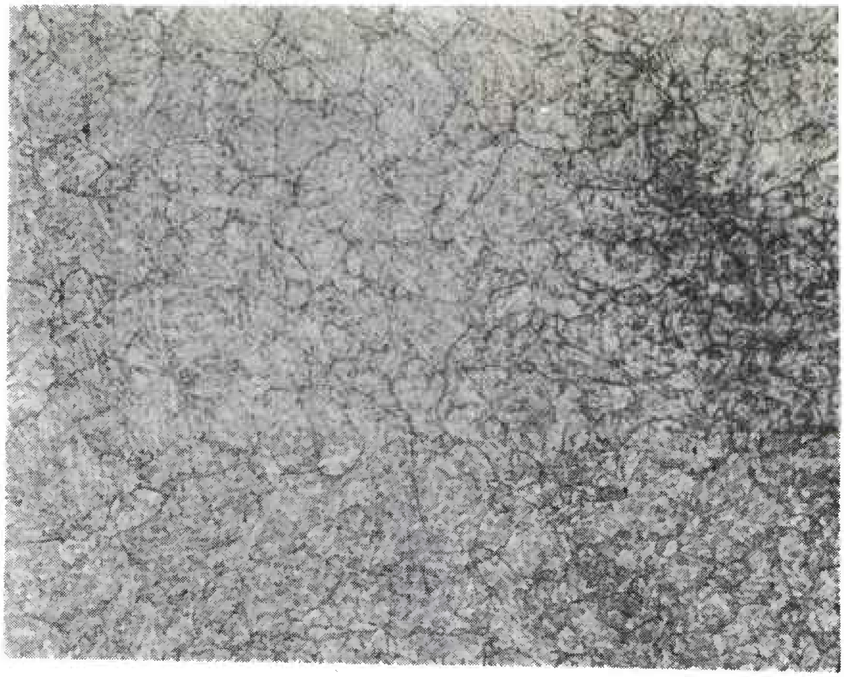


FIG. 17c - 0323 - Mid-Radius
500X - Tempered Martensite
(Not Normalized)

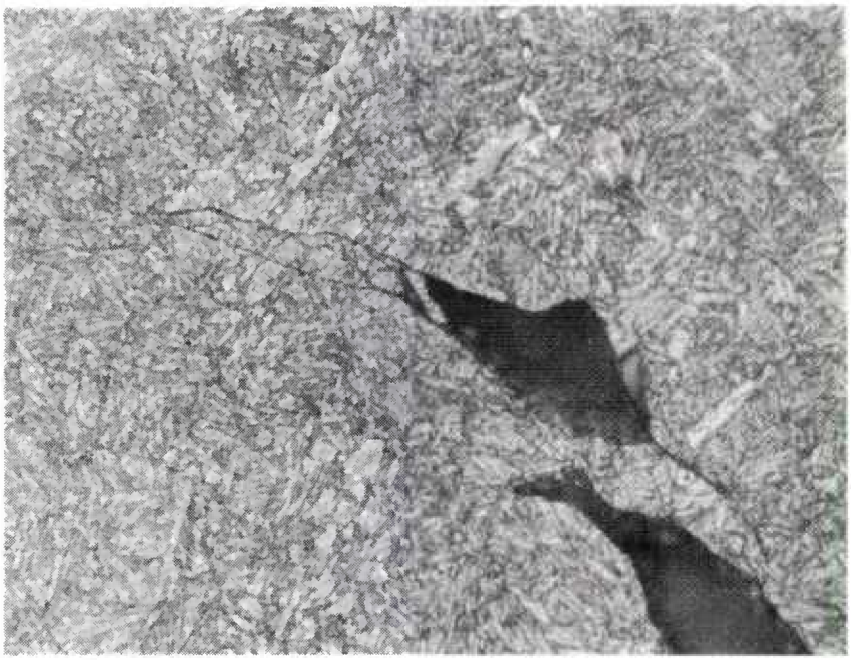


FIG. 17d - 0323 - Mid-Radius
1000X - Tempered Martensite
(Not Normalized)

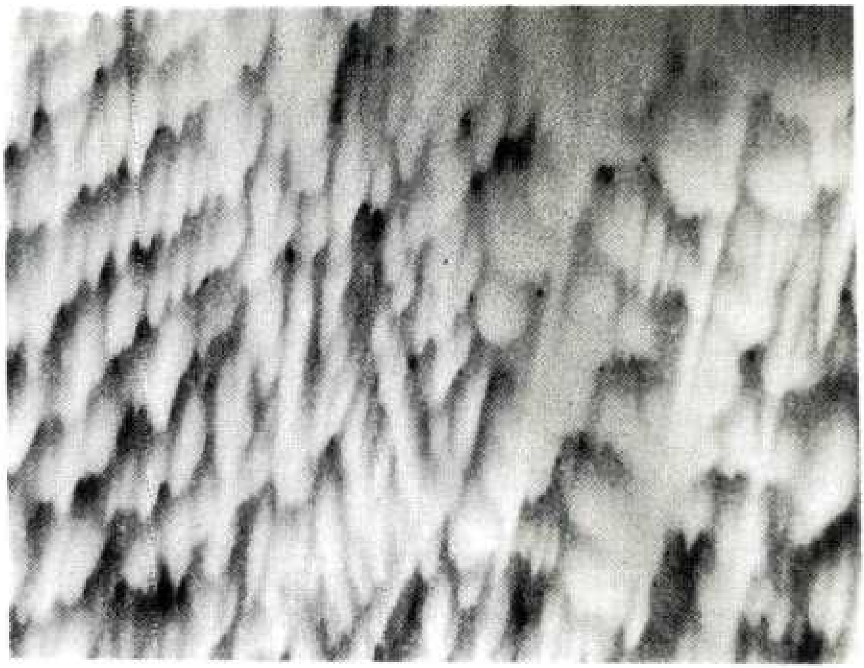


FIG. 18a - 0323 - Mid-Radius
20X - Residual Dendritic Structure
(Normalized)

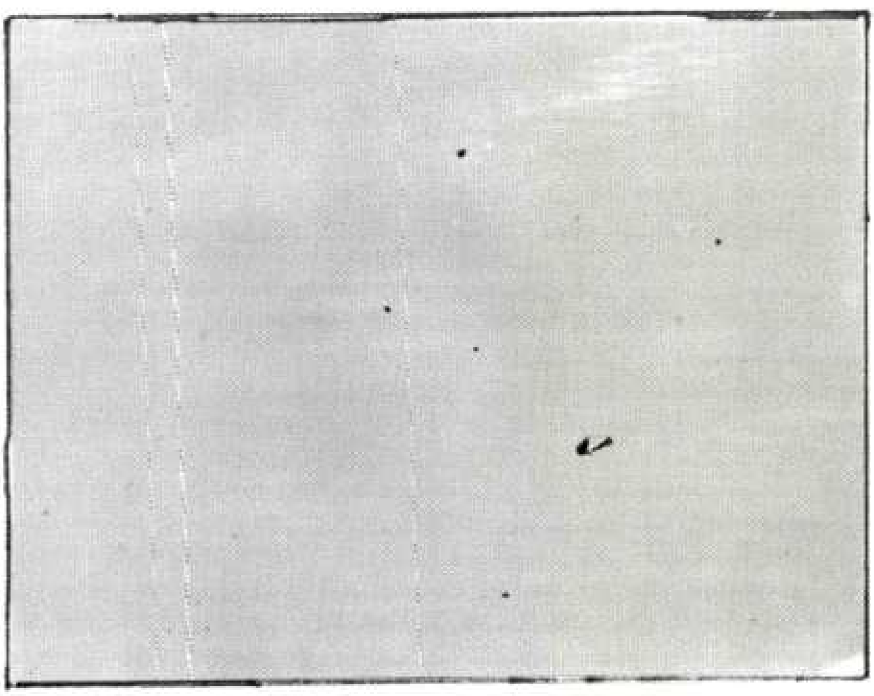


FIG. 18b - 0323 - Mid-Radius
100X - Inclusion Pattern
(Normalized)

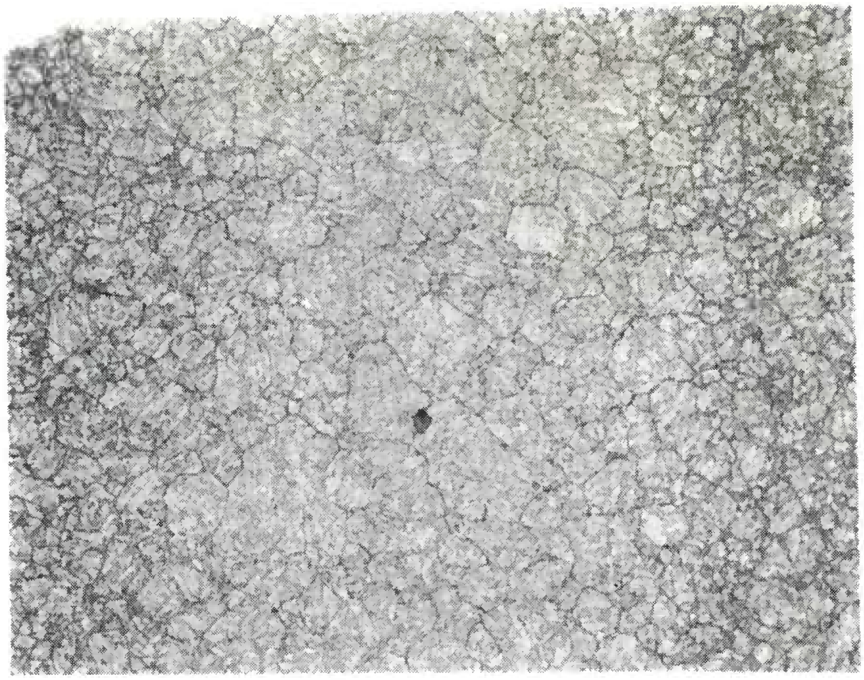


FIG. 18c - 0323 - Mid-Radius
500X - Tempered Martensite
(Normalized)

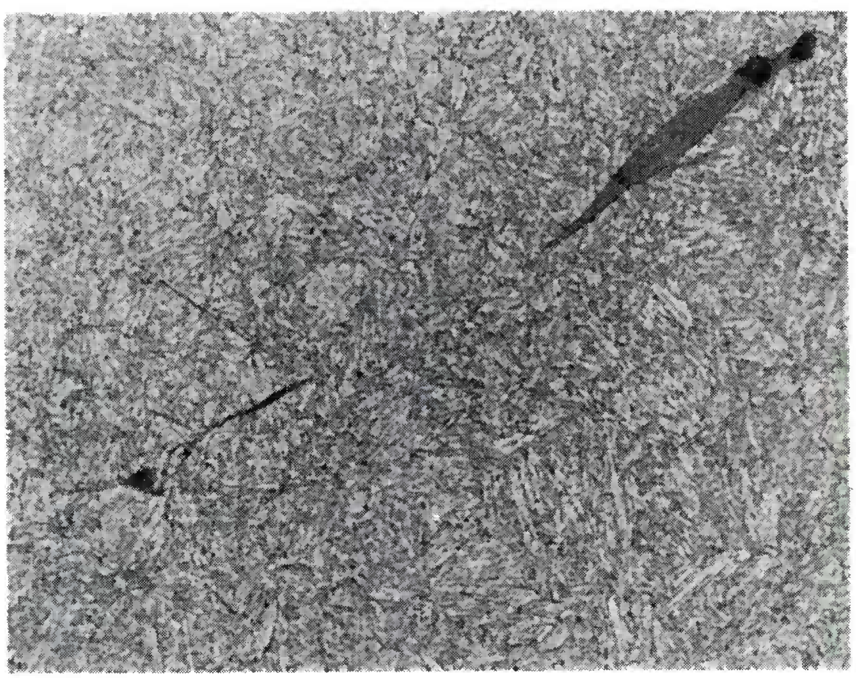


FIG. 18d - 0323 - Mid-Radius
1000X - Tempered Martensite
(Normalized)

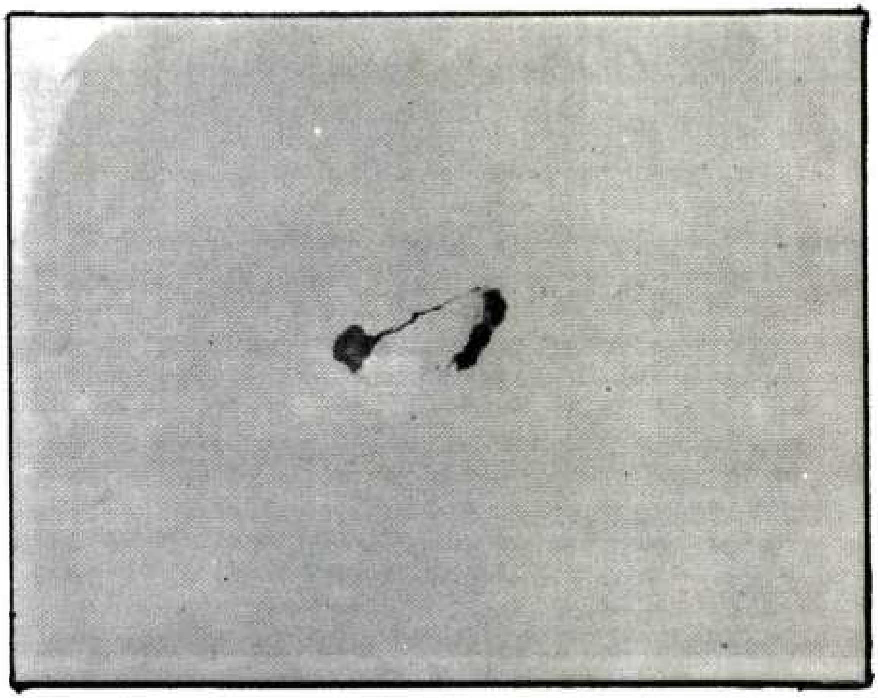


FIG. 18e - 0323 - Mid-Radius
500X - Large Inclusion in Test Bar
(Normalized)

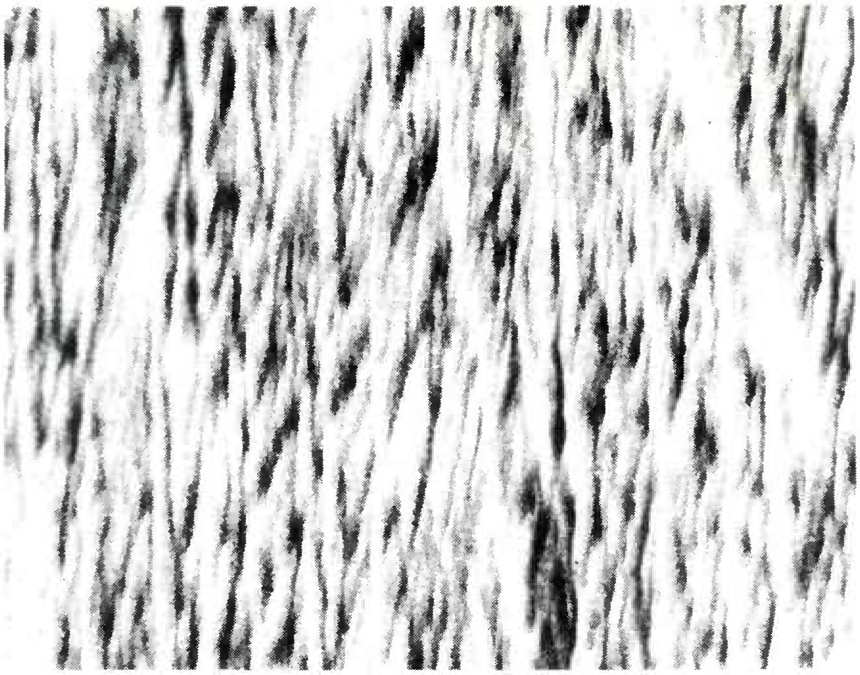


FIG. 19a - 0323 - OD
20X - Residual Dendritic Structure
(Not Normalized)

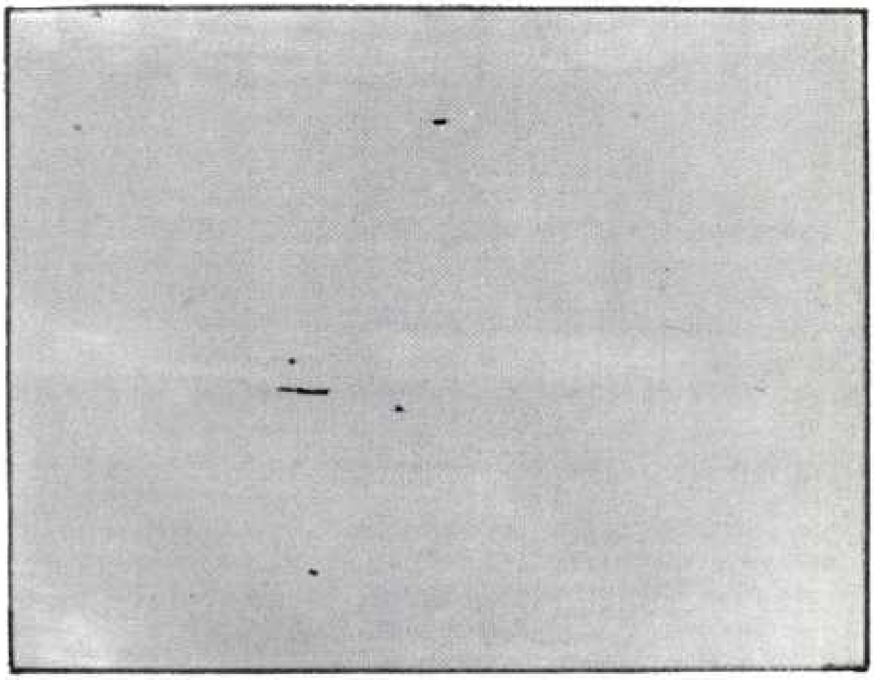


FIG. 19b - 0323 - OD
100X - Inclusion Pattern
(Not Normalized)

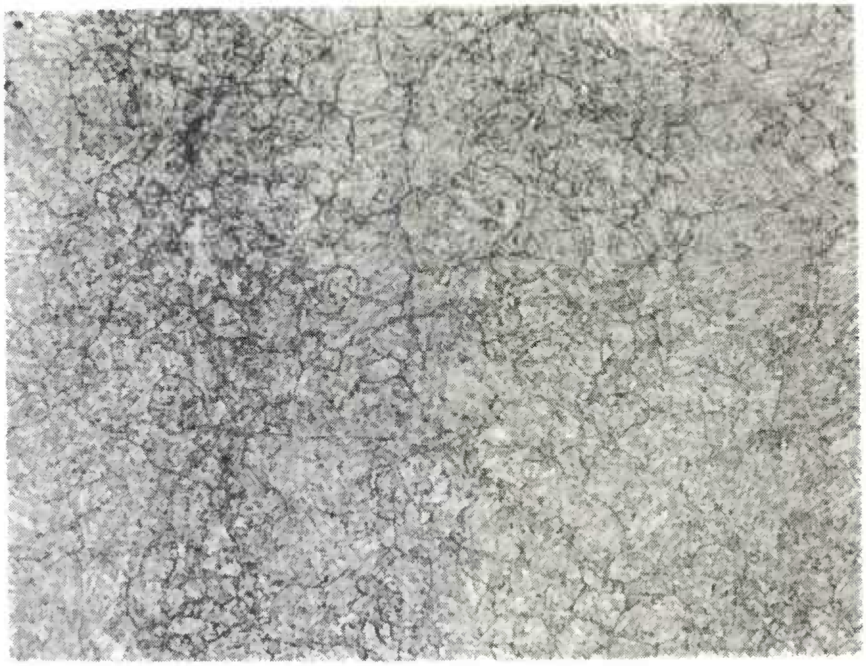


FIG. 19c - 0323 - OD
500X - Tempered Martensite
(Not Normalized)

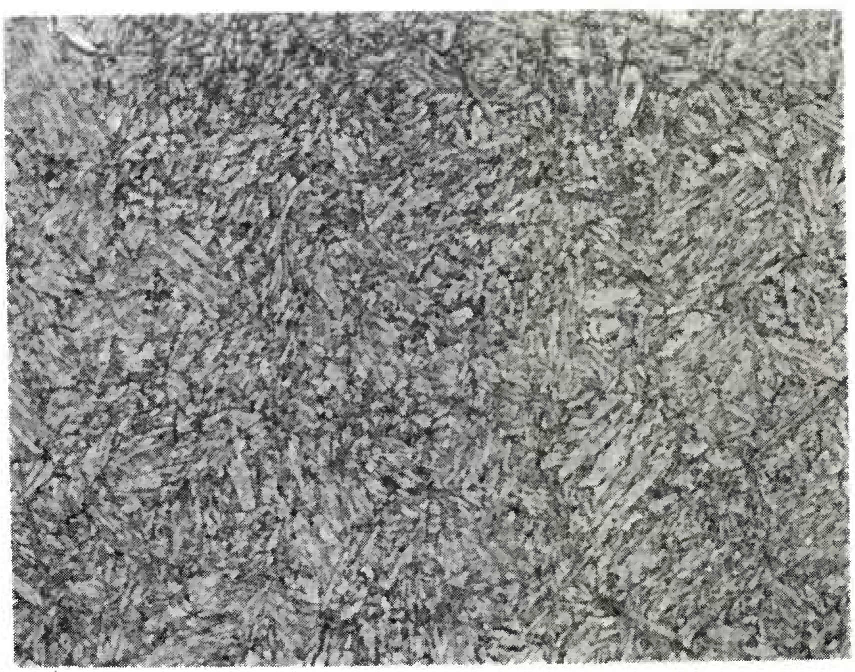


FIG. 19d - 0323 - OD
1000X - Tempered Martensite
(Not Normalized)

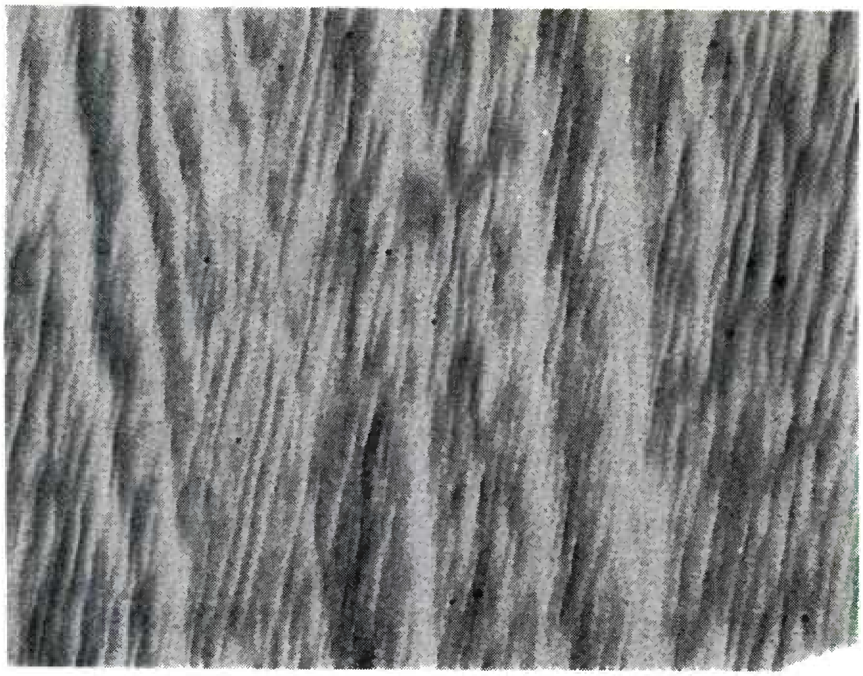


FIG. 20a - 0323 - OD
20X - Residual Dendritic Structure
(Normalized)

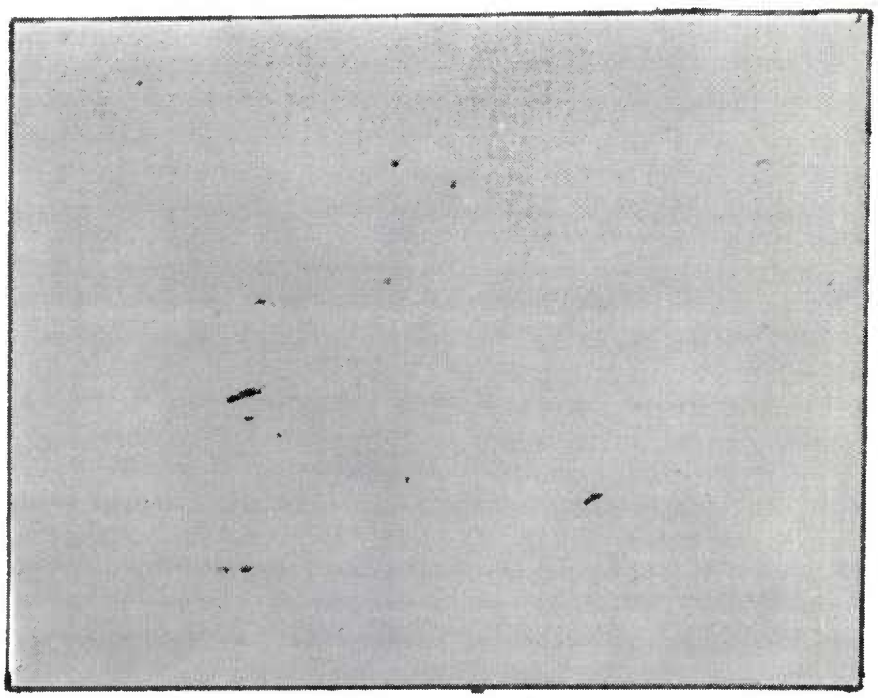


FIG. 20b - 0323 - OD
100X - Inclusion Pattern
(Normalized)

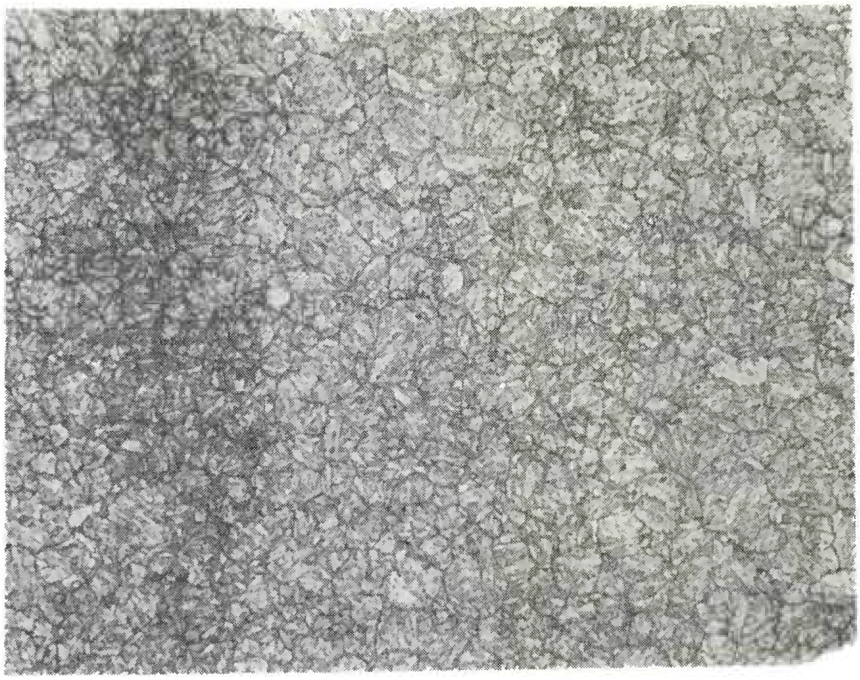


FIG. 20c - 0323 - OD
500X - Tempered Martensite
(Normalized)

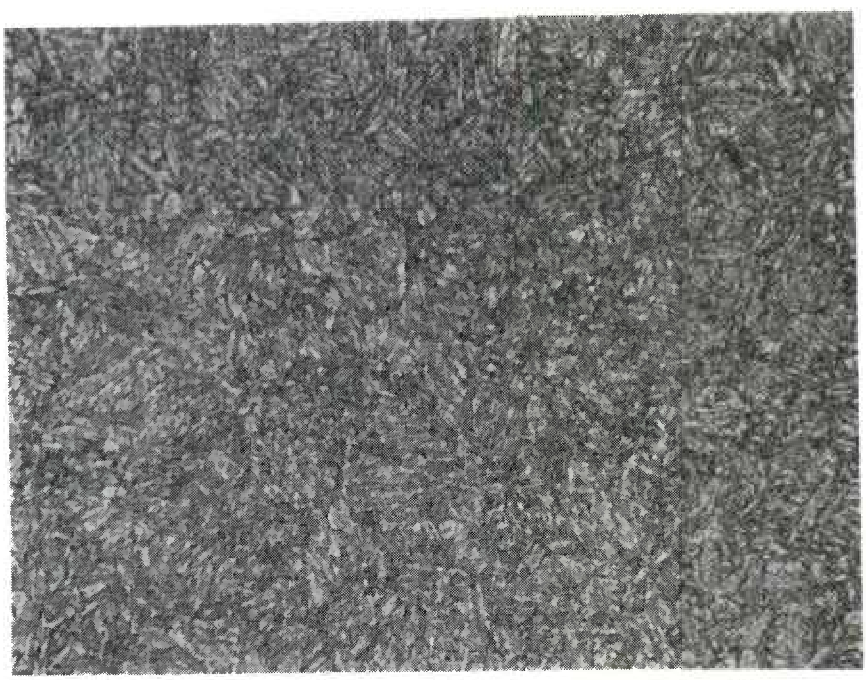


FIG. 20d - 0323 - OD
1000X - Tempered Martensite
(Normalized)

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